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Carbon Emissions Reduction and Power Losses Saving besides Voltage Profiles Improvement Using Micro Grids

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ABSTRACT

The objective of this paper is to evaluate the value of enhancement in voltage, amount of emission reduction and amount of power losses saving with using micro grids. The paper is divided in two parts, the first part evaluates the voltage improvement and power losses saving with micro (μ) sources (distributed generators like fuel cell, micro turbine, solar cell, wind turbine etc.). The obtained results indicate that using μ sources reduce voltage drop by about 3%, Also, it is found that using μ sources can reduce the power losses to more than one third of its value without using μ sources. The voltage at the buses near the μ sources location will suffer from small drop than the buses far from μ sources locations. The second part calculates amount of CO_2, SO_2, NO_x and particulate matters emissions from main grid and from μ sources which forms micro grid. The results indicates that more penetration of μ sources in the power systems especially the renewable sources (solar and wind) will help in reducing or removing emission problems and solve the green house gas problems. Finally this paper proved with calculations that the micro grid can solve most of the problems which facing the conventional power system and keep the surrounding environment clean from pollution and the micro grid will be the future power system.

Keywords: *Micro Grid, Voltage Enhancement, Losses Saving, CO_2, SO_2, NO_x and Particulate Matter Emissions*

1. Introduction

Increasing penetration of distributed generation (DG) resources to the low voltage (LV) grids, such as Photovoltics, CHP micro-turbines, small wind turbines areas and possibly fuel cells, alters the traditional operating principle of the grids. A particularly promising aspect, related to the proliferation of small-scale decentralized generations (μ sources), is the possibility for parts of the network comprising sufficient generating resources to operate in isolation from the main grid, in a deliberate and controlled way. These are called micro grids and the study and development of technology to permit their efficient operation has started with a great momentum [1-3].

With the efficient integration of small scale distributed generation into LV system and ability of supplying its own local demand customers, exporting energy to neighbor's systems and providing ancillary services (flow management, voltage and frequency control capabilities) to the public systems, the development of micro grids has potential to bring a number of benefits into the system in term of [4]:

- Enabling development of sustainable and green electricity: Clearly, electricity generated by renewable energy sources can substitute electricity supplied by conventional power plants with many benefits such as carbon emission reduction, reducing dependency on depleting fossil sources and sustainable and "free" energy sources which in the long term brings lower energy prices.
- Enabling larger public participation in the investment of small scale generation: Economic appraisal for installing micro generation will likely require less complex analysis in contrast to large generation. With much smaller magnitude in the investment, and less complexity in trading electricity, the financial risks exposed to the investors are much lower. At a domestic level, the decision to invest in such generation may be less motivated by financial gain and influenced by Individual's will to

contribute for clean environment. This will clearly enable larger public participation in contributing to the deployment of Renewable Energy Sources (RES) in the form of micro generation.

• Reduction in marginal central power plants: Micro generation can displace the capacity of peak load or marginal central power plants.

• Improved security of supply: With a considerable large number of installed micro generation, the total generation margin increases. This will also directly increase the available capacity of supplying peak load condition.

• With a large number of generators, failure in a number of small generators will not have a considerable impact on the capability of supplying the demand. This is in contrast to systems which rely on a relatively small number of big generators. A failure of one large generator may cause significant generation deficit and may lead to load shedding. Micro generation technologies also bring more diversity in the types of fuel that can be used to generate electricity. This is likely to increase the security of supply and reduce dependency on a particular type of fuel [5,6].

• Reduction of losses: Currently, losses in a system which primarily relies on central generation are typically around 7%-10% of total electricity consumption per year [4]. The magnitude of losses is influenced by many factors such as the proximity of generation to loads, circuit impedances, loads, and profiles of loading in each circuit among others. Bearing in mind that losses are a quadratic function of the current, the largest losses occur during peak loading conditions of the circuit. As micro grid is able to supply its loads locally, it reduces the amount of power transfer from remote generation via transmission and distribution circuits. Hence, it will reduce system losses. This also leads to the reduction of total energy produced by central power plants. Thus, it will also reduce Pollutants (CO_2, NO_x, SO_2 and other particulate matter) from these plants.

• Enabling better network congestion management and control for improving power quality: The introduction of micro generation in the LV networks will provide better capability of controlling power flows from the LV systems to the upper voltage networks. Hence, it may avoid the need for reinforcing the networks due to network congestion or voltage problems.

Based on the previous discussion, using micro grid will help on voltage improvement, emission reduction and power losses saving. Many papers discussed the effect of micro grid on voltage improvement, power losses reduction and emission reduction, but quantifying amount of improvement or reduction is not considered. The main goal of this paper is to evaluate the effect of the micro grid on voltage enhancement, emission reduction and losses saving. To conduct the proposed studies, the benchmark networks used for analysis and its data are described in Section 2 [single feeder and multi feeder networks]. Section 3 presents the daily load curves of the one feeder network (residential load) and three feeders network with three types of loads (residential, industrial and commercial loads). Section 4 shows the effect of the micro grid on voltage improvement and power losses saving for single feeder and multi feeders networks. Amount of emission reduction due to using micro grid is given in Section 5. Conclusions are stated in Section 6.

2. Benchmark Network Used for Analysis

Bench mark network described in references [3] and [7] is used for analysis. Single line diagram with all buses marked is shown at the end of the paper (**Figure 12**). One feeder network includes 7 buses (buses 1-7) represent the residential loads. Industrial load (bus 8) represents the second feeder. The remaining buses (buses 9-16) feed commercial loads and represent the third feeder. Impedance of the network lines, data for μ sources used and renewable power time-series used [output KW/Installed KW] are given in **Tables 1-3** respectively [7].

The units have been calculated in power base of 100 KVA and voltage base 400V. Bus 0 represents the main grid (distribution network).

Micro turbine is located at bus 7, fuel cell is located at bus 6, and PV_3 is located at bus 5 while wind turbine and $PV_{2\text{-}5}$ are connected to bus 4.

3. Daily Load Curves for Single and Multiple Feeders Networks

Aggregate daily load curves for single feeder (residential loads) and three feeders (residential, industrial and com-

Table 1. Line data for micro grid.

Sending Bus	Receiving Bus	R (p.u.)	X (p.u.)
0	1	0.0025	0.01
1	2	0.0001	0.0001
2	3	0.0125	0.00375
3	4	0.0125	0.00375
4	5	0.0125	0.00375
5	6	0.0125	0.00375
3	7	0.021875	0.004375
1	8	0.033125	0.00875
1	9	0.0075	0.005
9	10	0.015	0.010625
10	11	0.02125	0.005625
11	12	0.02125	0.005625
9	13	0.010625	0.005625
13	14	0.010625	0.005625
10	15	0.023125	0.00625
15	16	0.023125	0.00625

Table 2. Data of the used μ sources.

Unit ID	Unit Name	Minimum capacity (KW)	Maximum capacity (KW)
1	Micro tur-bine	2	30
2	Fuel cell	1	30
3	Wind	0.1	15
4	PV_1	0.05	3
5	PV_2	0.05	2.5
6	PV_3	0.05	2.5
7	PV_4	0.05	2.5
8	PV_5	0.05	2.5

Table 3. Renewable power time-series (Output KW/Installed KW).

Hour	Wind Power	PV-time series	Hour	Wind Power	PV-time series
1	0.364	0	13	0.494	0.318
2	0.267	0	14	0.355	0.433
3	0.267	0	15	0.433	0.37
4	0.234	0	16	0.321	0.403
5	0.312	0	17	0.329	0.33
6	0.329	0	18	0.303	0.238
7	0.476	0.002	19	0.364	0.133
8	0.477	0.008	20	0.373	0.043
9	0.424	0.035	21	0.26	0.003
10	0.381	0.1	22	0.338	0
11	0.459	0.23	23	0.312	0
12	0.39	0.233	24	0.346	0

mercial loads) are shown in **Figure 1**.

4. Voltage Enhancement and Power Losses Saving Evaluation with Using Micro Grid

Load flow program [8] is used to calculate the voltages at all nodes of the micro grid. Results are shown in **Figures 2-7**. The power factor is 0.85 lagging for residential and commercial consumers and 0.9 for the industrial ones. All calculations have been made at p.u of base V_{base} = 400 V and S_{base} = 100 KVA. The network data are presented in Sections 2 and 3. It has also been assumed that in the μ sources the power electronic interface has been adjusted to give or absorb zero reactive power at all buses except fuel cell and micro turbine buses. At all time, we assume that the micro turbine and fuel cell operated at 84% of their maximum capacity (25 KW), and the renewable sources outputs powers as listed in **Table 3**. The dashed lines represent results without μ sources while the solid lines represent results with using μ sources.

From the above results the following points can be raised:

- With using μ sources, in the two studied cases (single feeder and three feeder), the voltages at all buses are improved.
- Amount of improvement in case of single feeder network is better than three feeder case because amount

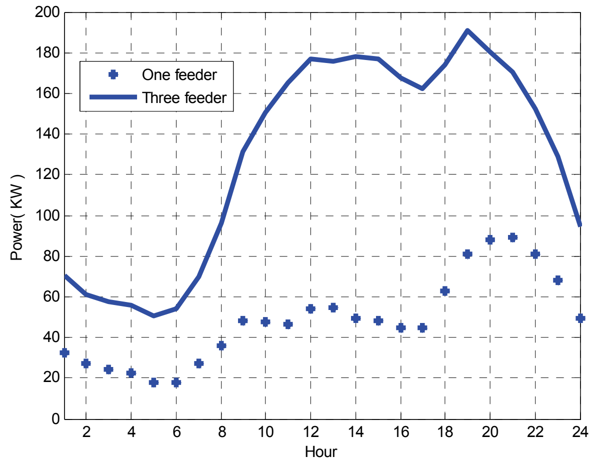

Figure 1. Daily load curves for one feeder and three feeders networks.

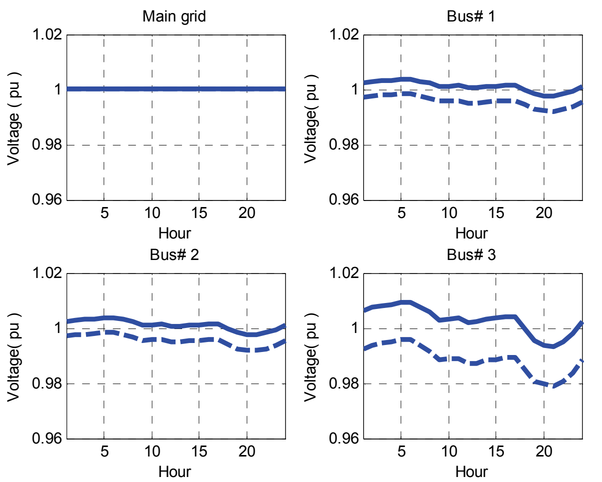

Figure 2. Voltage at buses 1, 2, 3 and main grid for single feeder network with and without using μ sources.

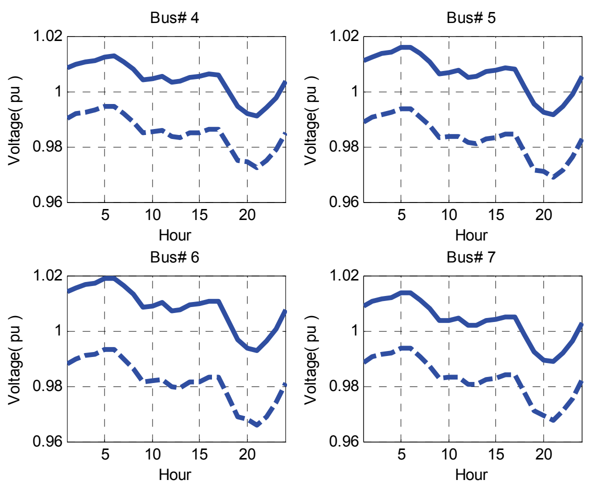

Figure 3. Voltage of buses 4, 5, 6 and 7 for single feeder network with and without using μ sources.

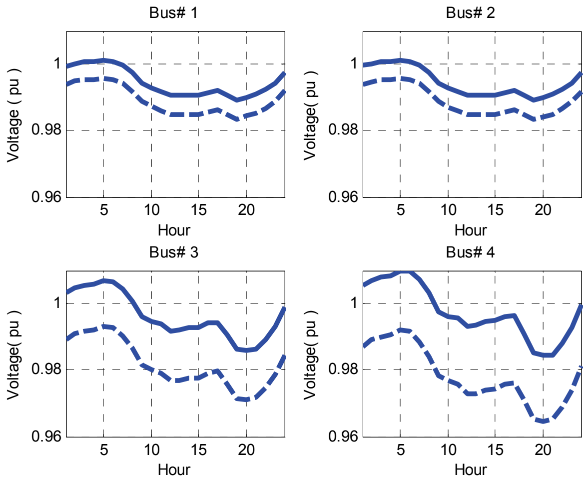

Figure 4. Voltage of buses 1, 2, 3 and 4 for three feeder network with and without using μ sources.

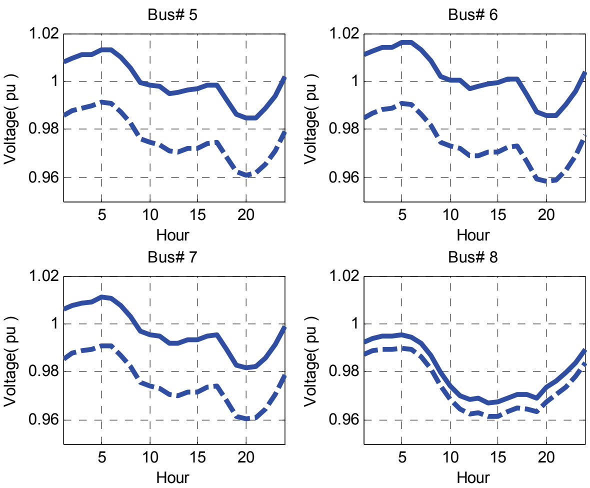

Figure 5. Voltage at buses 5, 6, 7 and 8 for three feeder network with and without using μ sources.

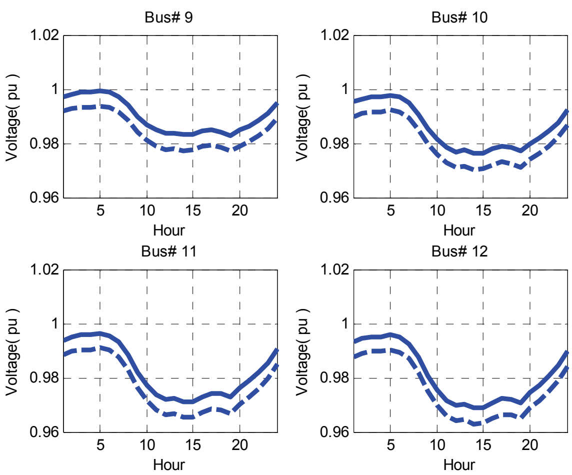

Figure 6. Voltage at buses 9, 10, 11 and 12 for three feeder network with and without using μ sources.

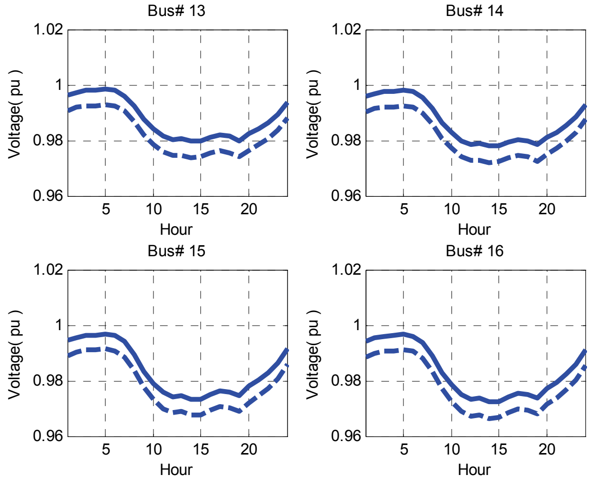

Figure 7. Voltage of buses 13, 14, 15 and 16 for three feeder network with and without using μ sources.

of power produced by the μ sources is less than the power demand by loads of the three feeder, also the μ sources are far from loads of industrial (bus 8) and commercial (buses 9-16) feeders.

- The largest drop of the voltage is about 4.5% without μ sources, because we assume that the voltage at the main grid (distribution network) equal to 1 p.u., if we assume that the voltage at the distribution network less than 1 p.u (due to voltage drop in the transmission network) as actually occur, the voltage drop without using μ sources will be more than 4% and may be reach to 8%.

The total power losses for one feeder and three feeder networks at the same conditions mentioned before are evaluated and the results are shown in **Figures 8** and **9**.

From the above figures, the following points can be summarized:

- The total power losses with using μ sources is less than the losses when μ sources are not used, because using μ sources reduces the distance between the load and generation and also, reduce the current flowing from the main grid. In addition, in our analysis, we calculated the losses in the transformer which connect the main grid with the micro grid network. If we take the losses in the upper distribution and transmission networks, the amount of losses will exceed the calculated value.
- For single feeder network, at lightly load μ sources production will feeds the load and export the remaining power to the distribution grid which make the losses with using μ sources larger than losses without μ sources.

5. Emission Reduction Evaluation with Using μ Sources

In order to evaluate the potential of environmental benefits from the micro grids, data about the emissions from

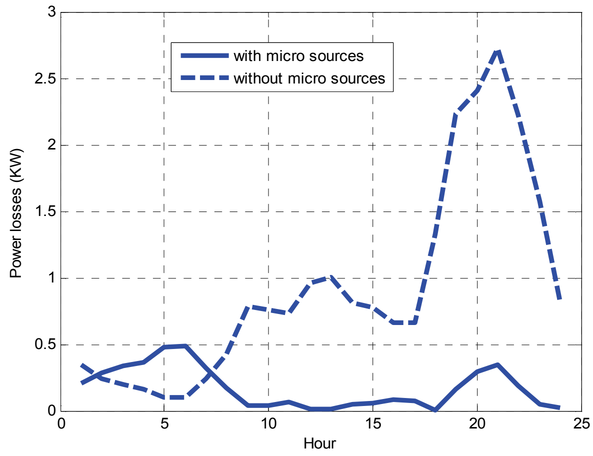

Figure 8. Total losses for single feeder network with and without μ sources.

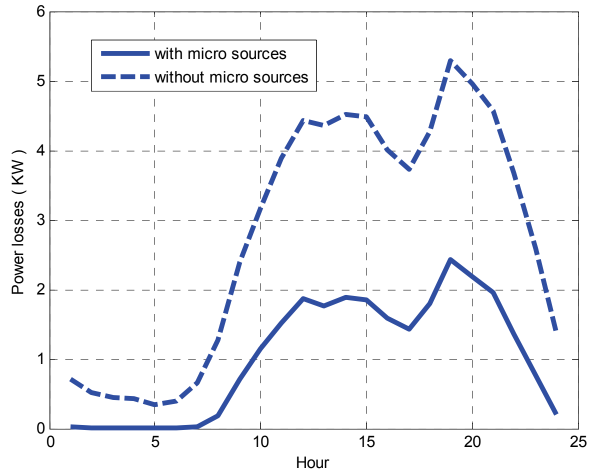

Figure 9. Total losses for three feeders network with and without μ sources.

the main grid and data about the emissions of the μ sources should be taken into account. The emissions for which calculations are made are: CO_2, SO_2, NO_x and particulate matters.

5.1. Emissions of the Main Grid

The production of the μ sources displaces power from the main grid. Thus the emissions avoided are an average value of the main grid emissions multiplied by the production of the μ sources. In our study, typical values of emissions have been used as shown in **Table 4** [7].

Table 4. Typical values of emissions from the main grid.

Pollutants	gr/KWh
CO_2	889
SO_2	1.8
NO_x	1.6
Particulate Matters	0.501

5.2. Impact of μ Sources

From the installed μ sources the ones that consume fuels have emissions which are significantly lower than the ones in the main grid. Where as the renewable such as wind and solar energies have zero emissions in their operation. It is assumed that the fuel burned by the Micro turbine and the fuel cells is natural gas. **Table 5** gives the data used for our analysis [7].

5.3. Results and Discussions

Amounts of emissions with and without using μ sources for single feeder and three feeder networks are shown in **Figures 10** and **11**.

According to the results obtained in the previous figures the following point can be summarized:

- Using μ sources has large effect in reducing the amount of emissions on CO_2, SO_2, NO_x and particulate matters, but the reduction in SO_2, NO_x and particulate matters is greater in percentage than CO_2 reduction due to the fact that the fuel burning units use natural gas that has lower emission levels in particulate matters, NO_x and SO_2 compared to thermal stations that use Heavy Oil.

Table 5. Typical emission data for μ sources.

Unit name	CO_2 coeff. (gr/KWh)	NO_X coeff. (gr/KWh)	SO_2 coeff. (gr/KWh)	Parti. Matters (gr/KWh)
Micro Turbine	724.6	0.2	0.004	0.041
Fuel Cell	489	0.01	0.003	0.001
Wind1	0	0	0	0
PV_1	0	0	0	0
PV_2	0	0	0	0
PV_3	0	0	0	0
PV_4	0	0	0	0
PV_5	0	0	0	0

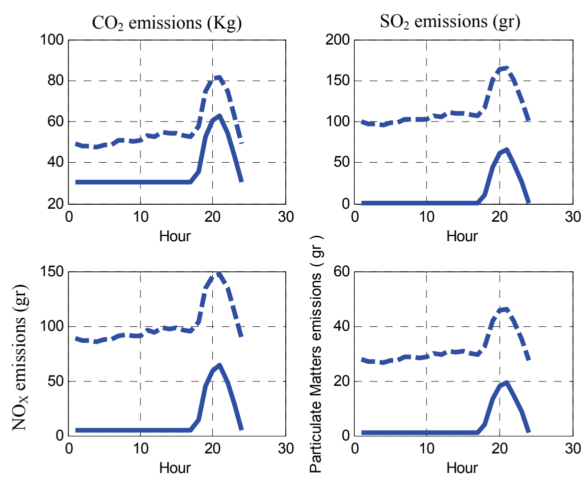

Figure 10. Amount of CO_2, SO_2, NO_x and particulate matters emissions for one feeder network with and without μ sources.

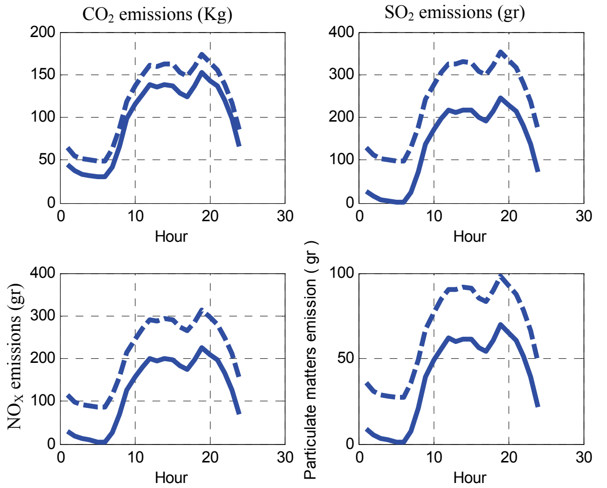

Figure 11. Amount of CO_2, SO_2, NO_x and particulate matters emissions for three feeder network with and without μ sources.

• In our study, the amount of power produced by renewable energy is small (15% of the μ sources power), if the renewable sources increases, amount of emissions reduction will be more than the value shown in the previous figures.

6. Conclusions

Distributed generation (DG) operation can improve the voltage profile in the micro grid nodes especially at the feeder where μ sources are installed. Therefore the installation of DG sources seems to be a solution in improving the voltage profile within a micro grid during times of low voltages (peak loads). It is found that when the power produced by μ sources sufficient to loads, the voltage drop at all buses has a negligible values, also, using micro grid will decrease the amount of power losses because the power which produced by μ sources will consumed locally with the load near from the μ

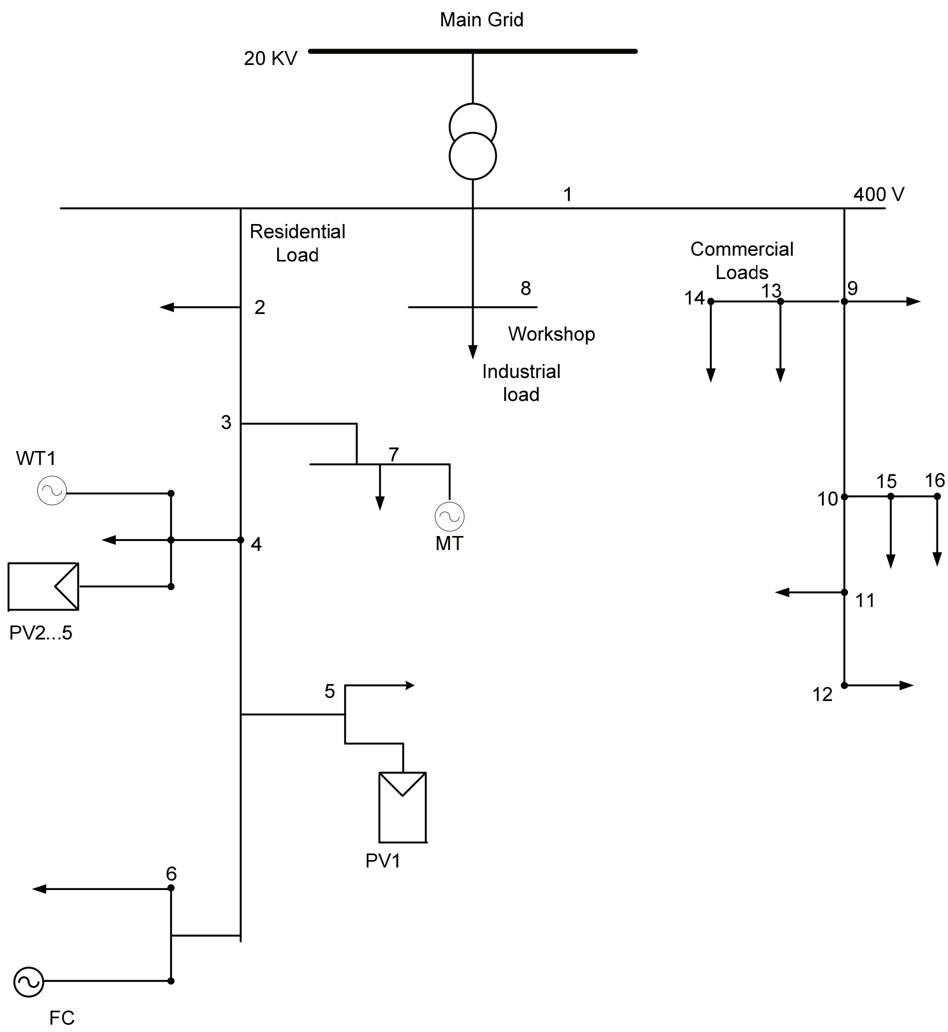

Figure 12. Single line diagram for three feeder network.

sources which prevent current from flowing or circulating in the networks transmission lines. Results showed that using μ sources has more effects in reducing all types of emissions especially when the μ sources contains many renewable sources such as wind and solar energy sources. The authors next step research aims to study the effects of micro grid in the dynamic performance of the main grid and how to use the μ sources to solve some of power system dynamic problems such as voltage stability, power quality and power system reliability.

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Behavioral and Technological Changes Regarding Lighting Consumptions: A MARKAL Case Study

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ABSTRACT

The present study aims at assessing the joint impact of awareness campaigns and technology choice, on end-use energy consumption behaviour. Actions to achieve energy savings through the use of more energy efficient end-use technology are included. A new MARKAL framework, the Socio-MARKAL, was recently proposed by the authors. As opposed to the traditional MARKAL framework based on technical and economic considerations, the Socio-MARKAL concept integrates technological, economic and behavioural contributions to the environment. This study takes into consideration, technological improvements on the demand side by consumers as well as behavioural changes minimizing carbon dioxide emissions and encouraging rational use of energy. The study presented in this paper, "Lighting Consumptions Habits in Geneva Households", was conducted from September to December 2009. *Based on the statistical analysis of this survey, we have determined coefficients to feed the database of the Socio-MARKAL model* (*an IEA/ANSWER database is available for testing purposes*).

Keywords: *Demand Side Management, Energy and Environmental Planning, MARKAL, Sociological Surveys, Sustainable Development*

1. Introduction

The original MARKAL model is a multi-period linear programming formulation of a reference energy system (RES). The constraints of the model describe all energy flows, production of electricity and centralized heat, industrial processes, consumption by end-use technologies and lastly energy services. The objective function in the linear programming model is the discounted sum, over the time horizon considered (usually between 30 and 45 years), of investment, operating and maintenance costs of all technologies, plus the cost of energy imports. The model also accounts for emissions of atmospheric pollutants (NO_x, SO_2 and CO_2) and is currently used in many countries and regions around the world for the assessment of energy pollution abatement policies. As the existing literature shows [1-4], the MARKAL family of models and similar energy optimization models to a certain extent are appropriate to answer questions such as: how do technologies and policies affect the environmental impacts of energy use (*i.e.*, GHG and emissions of other pollutants)? How do actions on the demand-side affect the supply-side and vice versa? How to model the dynamics of technology (e.g., the switch from one technology to another)?

However, among the existing MARKAL models, the social/sociological aspect of energy use on the demand-side is not taken into account. In particular, none of the above mentioned models takes into account the contribution of end use consumers' behavioural change as a reliable resource for energy efficiency, energy savings, and emissions reductions. Saving energy requires a change in the behavior of consumers, either to improve the energy efficiency of their technology (e.g., technology switch), or to improve the way they use energy with non-efficient technologies (e.g., better use of a less efficient technology). As such, information can be an important driver, as it can positively influence people's behavior towards energy and the environment [5]. Do we know enough about factors that can affect the behavior of energy consumers? Is it reasonable to integrate behavioral and techno-economic parameters? How behavioral parameters and data can be obtained?

Such considerations are accounted for in the Socio-MARKAL concept developed at HEG [6]. Behavioural contributions are modeled through virtual technologies built from sociological surveys, in order to capture the perception of the population in terms of attitudes and behaviors regarding energy consumption. These sociological and intangible technologies are therefore combined with traditional and tangible technologies. As a result of this combination, it will be possible to model the actual behavior of consumers as well as economically rational technology choices. These days, environmental/behavioral campaigns are becoming increasingly sophisticated, going far beyond standard information-only programs. Consequently, it is essential to define a clear and systematic protocol for socio-technological evaluations based on the Socio-MARKAL concept.

2. Protocol for the Socio-MARKAL

The Socio-MARKAL concept is based upon the introduction of a virtual technology built from sociological surveys. The purpose of such a concept is to capture consumers' perceptions towards their energy consumption trends, with an emphasis on their attitudes and behaviours. To this end, the virtual, *i.e.*, "sociological" technologies are associated with tangible technologies, allowing planners or analysts to model, analyse and assess the actual behaviour of consumers as well as technology choices which are economically rational. A detailed presentation of the Socio-MARKAL concept can be found in Fragnière *et al.* [6].

Below, we present a method for collecting social data in the context of the Socio-MARKAL project.

1) Hypothesis generation: qualitative research to identify potentials of behavioral change regarding energy consumption, handled through empirical methods (semi structured interviews, observations, social experiments). The energy-saving benefits (without a reduction in performance) as well as the essential character of behavioral change must be clearly explained. If the interviewees or respondents express interest in the campaigns, the awareness program must be designed so as to remove all the barriers – e.g. lack of information and motivation, cost of changing the technology, as well as its installation.

2) Hypothesis testing: survey research to test and measure hypotheses generated during the first phase (questionnaire, rank and sample statistical analyses).

3) Behavioral change scenario process: construction of long-term scenarios including behavioral change, in particular expert-built scenarios from the collected data.

4) Design: transformation of the Socio-MARKAL (abbreviated SOMARKAL in **Figure 1**) data and scenarios to feed the MARKAL data base.

The survey questionnaire is elaborated with the express purpose of assessing the potential contribution of behavioral change in end-use energy consumption pattern, and thereby in climate change mitigation. The methodology is structured as presented in **Figure 1**.

3. The Survey Research

The questionnaire can be constructed based on the consideration that climate change is due to greater energy use by humans. In line with this, two approaches apparently inclusive can be used [7]: 1) improving the efficiency of end-uses of energy and 2) not using or conserving energy. For Rudin, the proponents of the first approach seem to denigrate the overall notion of sufficient and limited energy use.

The main focus of this paper is on lighting technologies. Our survey is based upon the analysis of a sample (probabilistic) made up of 393 valid questionnaires addressed to the populations living along Lake Geneva. This research has been conducted by the laboratory of market research (LEM, Laboratoire d'Études de Marché) of Geneva Haute École de Gestion, whose objectives are to develop locally-based survey research in Economics and Business Administration and to train students to marketing survey techniques. The study presented in this paper, "Lighting Consumptions Habits in Geneva Households", was conducted from September to December 2009. In the questionnaire, we also included questions based on Contingent Valuation Methods (hypothetical scenarios) to assess the individuals' possible behaviors in specific contexts. Relationships between classes as well as relationships between variables have been investigated and analyzed in depth. Then, research hypotheses were verified on the basis of non-parametric statistical tests before being introduced in the Socio-MARKAL database. This survey questionnaire has been elaborated with the express purpose of assessing the potential contribution of behavioral change in end-use energy consumption pattern, and thereby in climate change mitigation.

The survey questionnaire was distributed to a random sample of people, equally distributed between men (52%) and women (48%). These individuals are aged between

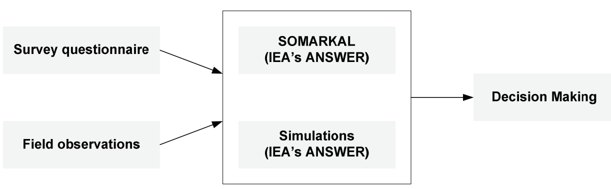

Figure 1. Outline of the methodology.

15 and 75 years old, with a mean of about 38 years old. They have the following occupations: employees (39%), students (31%), high-level executives (12%), independents and retirees, as well as housewives and unemployed (4% respectively). As for the ownership, 31% of the respondents own their house while 66% are tenants. Additionally, 68% live in apartments, while 32% live in a house. In this short paper, we just focus on some descriptive statistics. In particular, we present the results related to the question "What proportion of low consumption bulbs do you have at home".

Table 1 below indicates that, firstly, the great majority of the respondents (58.84%) have a proportion of low consumption light bulbs ranging between 25% and 75%. Secondly, the lowest response rates are on the extremes, namely those who have only low consumption bulbs (8.04%), and those who have none (14.83%).

The first observation shows that 58.84% of the population can potentially switch technology or change their consumption behavior through better use of incandescent bulbs. The corresponding maximum of incandescent light ranges from 25% to 75% of the bulbs.

However, 20% of the respondents responded "I don't know", which seems to indicate that they have no information about the technology (incandescent or not) they have been using for lighting.

Among other results provided, it is interesting to mention the following elements: 82.3% of the respondents indicates that they have been taught by their parents to switch off the lights when leaving a room; the respondents had also to give the most important peculiarities (2 choices) associated to a light bulb and it appears that "lighting intensity" is the most important one (26.8%), followed by "consumption" (22.0%), "lifetime" (20.2%), "purchase price" (10.6%). Summing up, economic parameters (lifetime, price and consumption) represent 52.8%, while parameters related to comfort (light intensity, color and ambiance) represent 40.3%. Ecological parameters (origin, manufacturing, and disposal) are of least concerns to the respondents (6.9%). The other questions have been designed in order to provide social data to these so-called virtual technologies in MARKAL.

The questionnaire includes questions on Contingent Valuation Methods (hypothetical scenarios) to assess individuals' attitudes and behaviors towards more efficient end-use technologies (*i.e.*, incandescent light bulbs vs. low consumption bulbs) (see for example [8-11]).

Based on this recent survey, we have determined an environmental and energy planning scenario that simultaneously takes into account technological as well as sociological aspects.

4. Modeling the Bulb Demand Devices in Socio-MARKAL

The representative parameters of the Socio-MARKAL have been designed so as to keep the traditional MARKAL formalism. This will ease the use of MARKAL platforms such as ANSWER. ANSWER [12] is the data base management system of the MARKAL-TIMES models generators developed by IEA-ETSAP, the International Energy Agency Implementing Agreement for a Program of Energy Technology Systems Analysis.

As mentioned on the previous sections, energy conservation may require the introduction/adoption of measures aimed at promoting rational use of energy. These measures include: 1) a better use and management of existing equipments or technologies and/or 2) technology switch. In this study, we assume that people/consumers who are willing to adopt one or more of these measures are driven by the desire to change their energy consumption behaviour. This willingness could be explained by many factors, such as their sensitivity to marketing/ awareness campaigns, training, their education, the quality of information they have been receiving, as opposed to the assumption of perfect economic rationality generally used in the traditional MARKAL family of models.

Behavioural change in Socio-MARKAL requires introducing virtual technologies, whose purpose is to trigger

Table 1. Summary statistics showing the proportion of low consumption vs. incandescent light bulbs.

Proportion of low consumption bulbs [%]	N, number of respondents	Percentage [%]	Percentage without "does not know" [%]	Cumulative percentage [%]
0	43	14.83	17.13	17.13
25	76	24.44	30.28	47.41
50	55	17.68	21.91	69.32
75	52	16.72	20.72	90.04
100	25	08.04	9.96	100.00
Does not know	60	19.29	-	-
Total	311	100.00	-	-

Note:
Number of questionnaires missing or not filled by the respondents. N = 82; Percentage: 20.87% in a total of 393 questionnaires

behavioural change among energy consumers. For the bulb demand devices section of the Socio-MARKAL model, we ended up with the following representation, using structures defined by MARKAL, as outlined in **Figure 2**.

We've got four demand devices. Parameters RLD1 and RLD4 represent the real and tangible lighting technologies, receiving electric power as input, and generating residential lighting.

Parameters RLD2 and RLD3 represent the virtual technologies.

As opposed to the real technologies, virtual technologies receive inputs that are intangible, leading to energy savings or technology switch. These devices are presented below:

- RLD1, "existing incandescent bulbs"
- RLD4, "existing low consumption bulbs
- RLD2, "moderate use of incandescent bulbs", and
- RLD3, "switch to low consumption bulbs"
- MRKRP2 and MRKRP3 are marketing/awareness campaigns which have the effect of changing the behaviour of energy consumers. MRKRP2 and MRKRP3 are respectively supposed to trigger the "Moderate use of incandescent light bulbs", and the behaviour towards low consumption bulbs, *i.e.* "Technology Switch towards low consumption bulbs".

5. Transforming Sociological Data into MARKAL Parameters: An Example

In this section, we show how the statistics obtained from the survey research are transformed to feed the bulb demand devices section of the Socio-MARKAL model. In this short paper, we will concentrate on a single case. Note that due to the qualitative nature of the data, we will be using a narrative scheme to make the case.

We have two sets of data for the residual capacities for incandescent bulbs RLD1 and low consumption bulbs RLD4. One data set comes from MARKAL data points that are obtained from statistics of observed actual contexts. The second data set about the number of bulbs and their split comes from the survey and it is not exact because it corresponds to elements of perceptions. The qualitative scale is defined over: zero, 1/4, 1/2, 3/4, all bulbs, and "do not know".

Residual capacity of behaviour change in favour of electricity savings RLD2 and for technology switch RLD3 is zero at the beginning of the optimisation. Then, we have the evolution of the environment that corresponds to Socio-MARKAL scenarios. For instance, there are people who will never change their behaviour and will only use incandescent bulbs RLD1 as long as they can buy them. Then, another case concerns people who are not aware of the advantages of low consumption bulbs and consequently might change their behaviour spontaneously as they get or receive more information.

Finally, there are people who would not change their behaviour without an information campaign; however with an exposure to information, they will start saving energy and/or switch technology. In order to measure this part of behavioural change, we have asked the following questions in the survey:

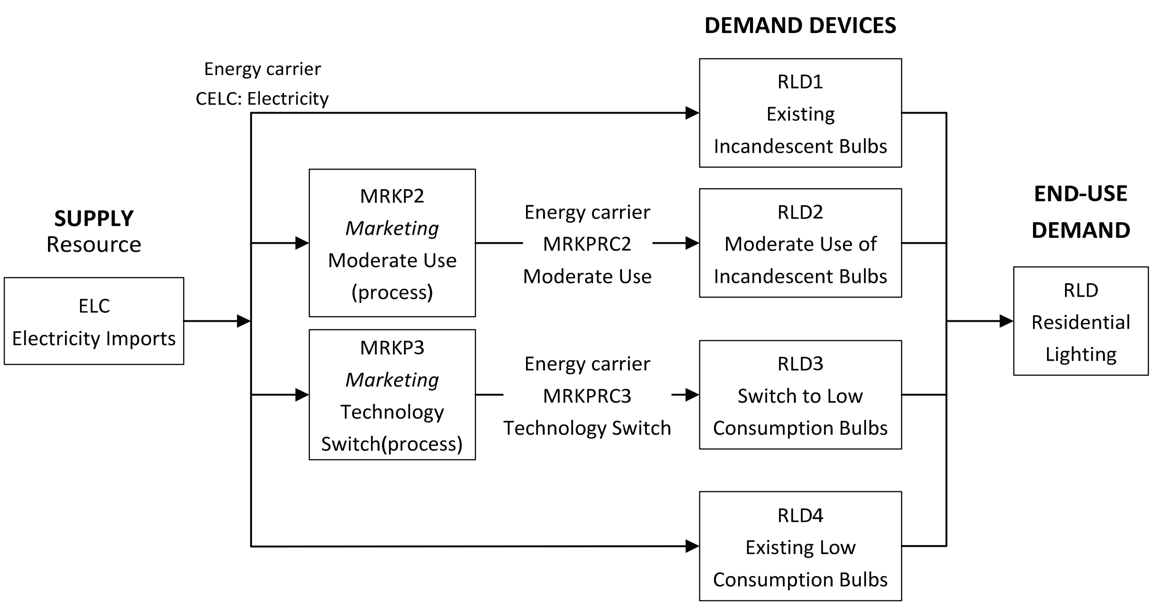

Figure 2. Structure of the reference energy system (RES).

- Question 10: “Did you know that low consumption bulbs may consume up to 5 times less energy than the incandescent ones?” (possible answers: Yes, No).
- Question 11: “Did you know that low consumption bulbs have a lifetime up to 10 times superior to the incandescent bulbs?” (possible answers: Yes, No).
- Question 12: “If you were better informed about the economic advantages of the low consumption bulbs, would you be ready to abandon completely the incandescent bulbs?” (possible answers: Yes, No).

Thanks to these questions, we can identify the part of consumers who were not informed about the energy consumption and lifetime of the technology. But once they got this complement of information, they claim to be ready to undertake technology switch. People who know about the advantages of low consumption bulbs and despite that, are not willing to change, influence the decrease of RLD1 to a steady incompressible level. For people who did not know about the advantages of low consumption bulbs and are then informed, there will be some of them switching to low consumption bulbs. We have then added one more question formulated as hypothetical scenarios:

- Question 13: “Did you know that if a household changes half of of incandescent bulbs for low consumption ones, about 200 CHF per year can be saved?” (possible answers Yes, No).
- Question 14: “Based on this information, would you change at least half of your bulbs?” (possible answers: Yes, No, I did it already).

This question enables us to identify the part of people who are well informed but will not change, those who were not informed but did the change and finally those who would do the technology switch thanks to the information.

In order to assess the drivers of energy savings, we have asked about the reasons why people turn the lights on when they enter into a room. If this is due to their poor eyesight or irrational fear of obscurity, they will probably not change their behaviour. However people who say it is just a habit, or if they do so for comfort, aesthetics, or do not know, they could possibly make the effort to change their behaviour. Likewise, people who say they leave light on when watching TV, could switch it off. But those who do have already done this or who leave only a small spot to reduce contrast and eyestrain, cannot make further savings. This is typically the kind of hypotheses we need to set up in order to get a proxy of the parameters that will be entered into the model.

For instance, in **Table 1**, related to Question 7 “What proportion of low consumption bulbs do you have at home”, we had roughly 20% who wouldn’t know about the number of low consumption bulbs they originally had. Based on cross table analyses involving different questions of the questionnaire, and referring to the above hypotheses, we propose a new presentation for the proportion of low consumption bulbs in **Table 2** above. This table is now usable to determine the RESID of RLD 1.

6. Preparing the Data for Socio-MARKAL

This section aims at determining the parameters for all the demand technologies (*i.e.*, RLD1, RLD2, RLD3, RLD4) presented in **Figure 2**. More descriptive details about these technologies can be found in the appendix, in **Table 5**. We start with RLD3, which corresponds to “Switch to low consumption bulbs”.

6.1. The Case of RLD3

Our evaluation is based on the cross-analysis of questions 13 and 14. The respondents (3.9% of the sample and 15.3% of people who answered “Yes” to question 13) were already informed about the economic advantage of choosing low consumption bulbs and are not willing to change. These respondents represent an incompressible ratio that enters into the efficiency coefficient of the MARKAL model. To this figure, it is necessary to add 14.4% of the sample (*i.e.*, 19.2% of people who answered “No” to question 14). These latter persons did not have the information before and were informed during the survey. Still, they indicate that they won’t change their behavior.

On the other hand, 9% of the sample and 35.7% of the people answering “Yes” to question 13 were already informed about the economic advantages of switching to low consumption bulbs. Moreover, they indicate that they are willing to make a technology switch soon, but did not do it yet. We believe that for these respondents, this new exposition to information represents a reminder. Likewise, 44.2% of the sample (*i.e.*, 59.1% of all people for whom the information is new) claim that they are willing to undertake the technology switch in order to replace half of their incandescent light bulbs by low-consumption bulbs.

Finally, people who have announced that they already made the change before the survey, are deducted from

Table 2. Descriptive statistics showing the proportion of low consumption light bulbs.

Proportion of low consumption bulbs [%]	N, number of respondents	Percentage [%]
0	53	17.04
25	96	30.87
50	65	20.90
75	72	23.15
100	25	08.04
Total	311	100.00

the final ratio that is inputted in MARKAL (53.2% of the people who answered "Yes" to question 14).

6.2. The Case of RLD2

Here we explore and analyze the answers in question 15, "Your electricity consumption would likely change for the following reasons" (respondents can make up to 2 choices among six options). The results (normalised) are presented on the table below.

In order to determine the parameters for RLD2, we have considered three different aspects. Firstly, we have decided to evaluate the direct impact of an advertising campaign (*i.e.*, "An information campaign on the media or advertising") as our main explanatory parameter for RLD2. Secondly, the indirect effect can be represented by both "The opinion of a relative" and "A request from our children". Thirdly, economic criteria include the income modification (*i.e.*, "A change in your income"), and "Electricity price increases". The former and the latter are excluded because these parameters (effects) are in fact characterized by their economic rationality, which is compatible with the standard MARKAL formulation.

Our evaluation shows that 37.5% of all respondents (24.7% of the normalized total, as shown in **Table 3** above) declare that an awareness campaign can influence their electricity consumption. Based on this information, we can set the *efficiency of the awareness campaign* to 24.7%. Setting the efficiency as composed of both the direct and indirect effects, we get 27.5+37.5+11.1 = 76% of all replies (*i.e.*, 50.2% of the normalized total). However this figure represents the declared likeliness of the respondents influenced directly by an information campaign or indirectly through a third-party person (*i.e.*, relatives and parents).

6.3. Determining Investment Costs for MRKP2 and MRKP3

The following table corresponds to the results provided for question 16, "What kind of information means would likely change your behaviour". These results, presented in **Table 4** below, are associated with percentages that have been normalised. In this table, we have included a new column titled "Cost per individual". These estimates represent calculations based on the results of question 16 and hypotheses related to marketing costs (obtained through a discussion with a marketing expert operating in the Geneva region). In the case of articles from newspapers, we consider the cost to be zero because it is an independent editorial initiative.

6.4. Inputting the DM Tables of MARKAL

We have implemented a MARKAL model using ANSWER, the IEA platform. Consequently this kind of simulation will be directly available to ANSWER users and we hope that it will enable them to develop their own Socio MARKAL scenarios (the IEA/ANSWER mdb file of the case study presented in this paper is available by contacting the authors).

The following snapshot, exhibited in **Figure 3** below, presents an example of this kind of Socio-MARKAL

Table 3. Distribution of responses to question 15, "Your electricity consumption would likely change for the following reasons" (respondents can choose among up to 2 options).

	Proportion of respondents (N = 311)
Option 1. The opinion of a relative, a friend or a neighboor	18.20
Option 2. A request from your children	7.27
Option 3. An information campaign on the media or advertising	24.74
Option 4. A change in your income	12.53
Option 5. Significant electricity price increase	30.71
Option 6. Nothing would change my behaviour	6.62
Total	100.00
Aggregates	
Information (options 1 to 3): 50.13%	
Economic conditions (options 4 & 5): 43.25%	

Table 4. Distribution of responses to question 16, "What kind of information would likely help changing your behavior".

Means	Percentage [%]	Cost [CHF] per individual
A Web page filled with useful information	10.50	5.00
A Web page with an energy savings calculator	17.60	5.83
Articles from newspapers/TV reports	19.40	0.00
Leaflets from utilities or green organisations	14.50	0.03
Doorstep awareness campaigning	2.40	20.00
Selling points with information (e.g. posters)	12.30	20.00
Advertisement on TV and radio	14.20	1.00
Advertisement campaigns on public transports	9.10	0.25
Total	100	

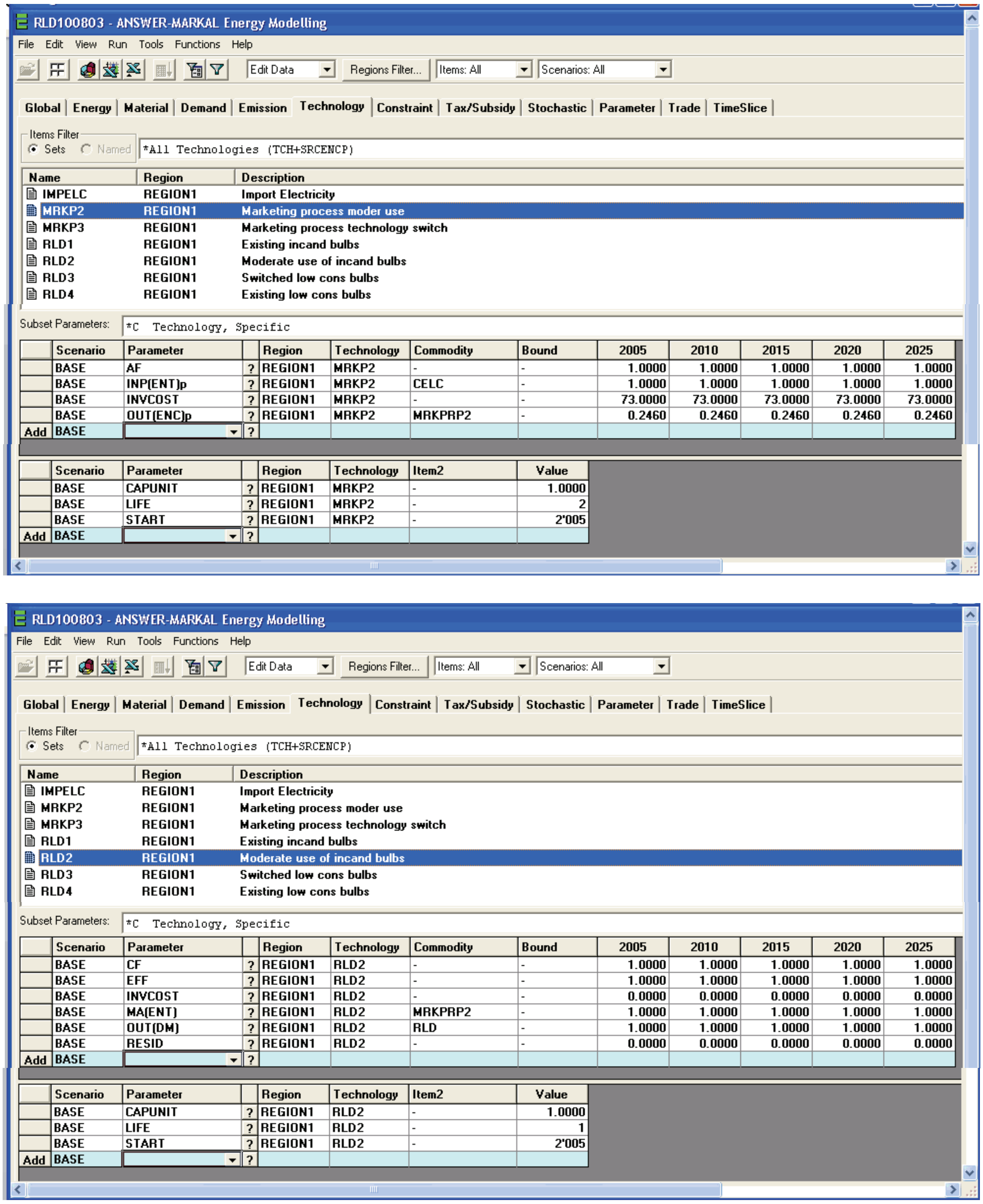

Figure 3. Example of Socio-MARKAL scenarisation developed in IEA's ANSWER.

scenarisation in IEA's ANSWER. We are aware that this kind of scenarisation is associated with uncertainties and that this kind of development is still in its infancy. However, it offers to policy makers a tool to test environmental policies that involve social change.

Recently, new regulations imposing low consumption bulbs have been enforced in the EU as well as in Switzerland. Consequently, this kind of scenario can be useful to understand alternate evolutions if this kind of regulations were not in place.

We have seen that it is particularly difficult to devise hypotheses regarding investment costs. We would like also to remind that it is possible to produce shadow prices from MARKAL, because it is based on convex optimization. So, it is always possible to determine what should be "the rational" cost of awareness campaigns.

7. Illustration

In this section, we will assess the Socio-MARKAL model with an illustration based on three scenarios. In this illustration, we consider an evaluation over a span of 20 years (*i.e.*, from 2005 to 2025) spread over 4 periods of 5 years.

7.1. Assumptions

A number of assumptions have been introduced, specifically regarding both the demand investments for residential lighting technologies.

The overall *demand* for light bulbs is expected to grow by about 50% over the evaluation period, *i.e.*, from 1442 hundreds units (144'200 bulbs) in 2005 to 2500 hundreds units (250'000 bulbs) in 2025. Residual capacity is split between RLD1 and RLD4, respectively for 80% and 20%.

*Investment cost*s for RLD1 are expected to rise by 40% over the evaluation period, *i.e.*, from 1 CHF/bulb in 2005 to 1.40 CHF/bulb in 2025. However, for low consumption bulbs (RLD4) whose costs are set to 10 CHF/bulb in 2005, we assume decreasing costs over the time periods of respectively, 7 CHF/bulb in 2010, 6 CHF/bulb in 2015, 5 CHF/bulb in 2020, and 4 CHF/bulb in 2025.

The *lifetime* of new light bulbs is set to 1 year for incandescent bulbs (RLD1) and 2 years for low consumption bulbs (RLD4).

The e*nergy carrier input,* (*i.e.* MA (ENT) in ANSWER), remains constant over the evaluation period. For RLD1 and RLD4, it is set to 0.0328 TJ/unit and 0.0065 TJ/unit respectively.

7.2. Scenarios and Results

We consider three scenarios.

Scenario 1: the first scenario (see **Figure 4**) is characterized by investment costs in marketing technologies which are so high that virtual technologies do not appear in the optimal solution. Here, we have a case of classical MARKAL competition between incandescent bulbs (RLD1) and low consumption bulbs (RLD4). Both technologies have bounds. In the case of incandescent bulbs, there is a constraint related to the proportion of people who claim they are not willing to undertake the technology switch, *i.e.*, from incandescent to low consumption bulbs. On the other hand, for low consumption bulbs, we have put a lower bound equal to the installed capacity on the first period, assuming that in the following periods, their penetration should never go below that value.

Scenario 2: the second scenario presented in **Figure 5**, is an example of a case when the cost of information campaigns in favour of technology switch is getting lower so that the campaigns are worth to be financed. In this case, and for two periods, the number of incandescent bulbs decreases, replaced by low consumption bulbs, which appear as the result of the campaign in favour of low consumption bulbs.

Scenario 3: the third scenario (**Figure 6**) shows that if the cost of marketing technologies is low, then the energy savings and technology switch may dominate the spontaneous purchase of real bulbs.

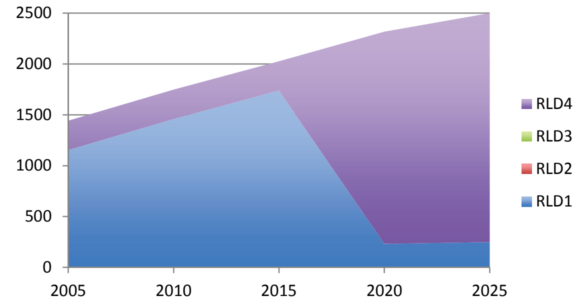

Figure 4. Outline of scenario 1, "Marketing technologies too costly".

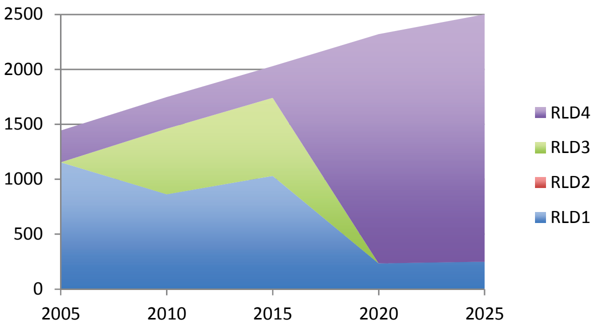

Figure 5. Scenario 2, "Marketing for technology switch becomes competitive".

8. Conclusions

This study implements the Socio-MARKAL framework that would take into account consumers' technological

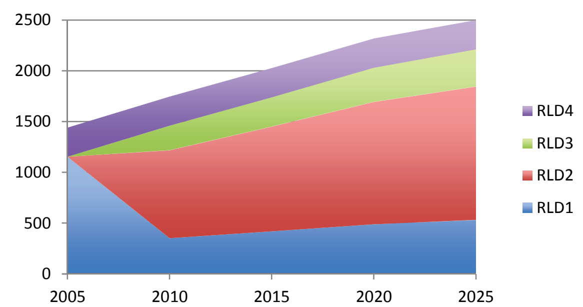

Figure 6. Scenario 3, "Both marketing technologies appearing in the optimal solution".

improvements and behavioral changes minimizing carbon dioxide emissions and encouraging rational use of energy. In this paper, we firstly present and discuss the results of a survey research related to attitudes and behaviors towards lighting consumption.

We show how to transform the sociological data into parameters for the MARKAL model. Secondly, we prove with this paper that, sociological data can be integrated in a model of technological choices such as MARKAL. The IEA's platform, ANSWER, has been used for that. Thirdly, our study shows that it is possible to develop environmental and energy planning scenarios that simultaneously take into account technological as well as sociological aspects. This study also shows that we have been able to move from an idea (*i.e.*, integration of behavioral aspects of energy consumption into a model of technological choices) to the concept proven (*i.e.*, the Socio-MARKAL).

We are currently working to extend the concept to the transportation sector. A new sociological survey about attitudes and behaviors regarding passengers is currently conducted in order to feed the Socio-MARKAL model with additional relevant data.

The conclusions drawn from one of our previous studies [10] show that the sociological/behavioural approach, *i.e.*, data collection through surveys and sociological experiments are powerful tools that can help people understand their (personal) energy use and for motivating their actions to reduce carbon emissions. This means that awareness campaigns can stimulate behaviour change to conserve energy. Consequently, both technological and behavioural contributions can be integrated into a single strategy. In turn, this is enough to justify an extension of the current MARKAL family of models, with the integration of data collected through surveys and/or awareness campaigns.

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Appendix

Table 5. Technologies and their description.

Parameters	Value	Units	Type
ELC	Energy imports	TJ	Resource
CELC	Energy carrier	TJ	Resource
MRKP2	Awareness campaign "Moderate use of incandescent light bulbs"	CHF/capacity unit	Process technology
MRKP3	Awareness campaign "Technology switch towards low consumption bulbs"	CHF/capacity unit	Process technology
MRKPRC2	Energy carrier MRKP2	TJ	Process
MRKPRC3	Energy carrier MRKP3	TJ	Process
RLD1	Existing Incandescent Bulbs	Hundreds of light bulbs	Demand device
RLD2	Moderate Use of Existing Incandescent Bulbs	Hundreds of light bulbs	Virtual demand device
RLD3	Technology Switch toward Low Consumption Bulbs	Hundreds of light bulbs	Virtual demand device
RLD4	Existing Low Consumption Bulbs (a mix of new technologies)	Hundreds of light bulbs	Demand device
RLD	End use residential lighting	Hundreds of light bulbs	Demand

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Geothermal Water in Lebanon: An Alternative Energy Source

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ABSTRACT

Recently, demand for energy has been increased worldwide, notably in the view of high economic value and competition of fossil fuel, as well as the negative impact of fuel consumption through carbon release, and thus the consequences on human health and environment. Various aspects of energy sources into Earth's crust have been discovered and utilized. Geothermal energy is one aspect of these sources where they have been well pronounced in many countries and proved to be a potential energy source for the future needs. Lebanon, the country with rare natural energy, the renewable energy sources are almost ignored and there is only limited utilization of hydro-power, wind and solar energy, whilst oil imports occupy a substantial portion for energy use. Yet, geothermal energy has not raised and no concern has been given to this renewable source. Meanwhile, there are several indicators showing the existence of geothermal water in different regions in Lebanon. They almost occur where basalt rocks are exposed. This was evidenced whether from water in drilled wells or from various discharging springs, as well as indications of thermal water was observed also in many localities along the Lebanese coastal water. This study shows the available information in this respect, considering the occurrence of geothermal water in Lebanon as an alternative energy source. Thus four major geothermal domains were recognized. The study introduces detailed characterization on the existing aspects of geothermal water and inducing its hydrologic regime and mechanism of groundwater heating. It would be a reconnaissance stage that may help applying further detailed assessment.

Keywords**:** *Hot Water, Springs, Alternative Source, Lebanon*

1. Introduction

Energy has become an utmost need for human life and any shortage in energy supply will result a serious national problem, notably with the increase of population size that accompanied with high standard of living. This in turn motivated many countries to search for alternative energy sources other than fossil fuel, which is a depleted source and often results negative environmental aspects. Recently, the geothermal energy has become one aspect of these alternatives. Rough estimates indicated that geothermal energy can cover the world's need of energy for the next 100000 years [1]. This is well pronounced in the United States where geothermal energy is supposed to supply 10% of electricity needs by the year 2050.

Even though, almost everywhere in the upper 10 feet of the Earth's surface maintains a nearly constant temperature between 10°C and 16°C, yet there is higher heat that released from deep Earth and composing a renewable sort of energy, which is a clean and sustainable resource that occurs at depths everywhere beneath the Earth's surface and ranges from few meters in certain areas to a few kilometers (5 to 8 km) beneath the Earth's surface and reaches down even deeper to the extremely high temperatures of molten rock called magma.

There are several potential uses for geothermal energy, but it is mainly used to heat buildings, as well as in generate electricity. While, the exploitation procedure implies drilling wells into underground reservoirs. In this regard, there are several techniques used to tap geothermal sources, and it mainly involves injecting cold water down into wells, circulating it through hot fractured rocks, and drawing off the heated water from another well. Currently, this technology is still with less commercial benefits. The existing technology also does not allow recovery of heat directly from magma, the very deep and powerful source of geothermal energy.

Lebanon, the Middle Eastern country with relatively small area (~10400 km^2), lacks to local energy sources, and demand for renewable energy has been exacerbated.

For this reason, Lebanon imports around $500 million worth of fuel annually to generate the electricity needs [2] and yet there is a shortage in electrical power supply. In addition, there are no studies to assure the existence of potential fossil fuel for energy generation, except few prospects, such as those on uranium [3].

There are several aspects of renewable energy sources that can be utilized in Lebanon. These are attributed, in a broad sense, to hydro-power, wind, solar and geothermal energy. Hydro-power sources have been used in Lebanon since few decades, such as that in Qaraoun Lake in the Bekka region, but they neither implemented over wide geographic areas nor developed to fulfill their power as an integral source for energy. While, wind and solar energy are almost applied on limited and local basis, since they do not follow a strategic plan with wide range of application. Therefore, oil products are still the principal energy source in Lebanon and they compose about 93.5% of energy supply according to obtained estimates in 2003 (**Figure 1**).

Yet, there is no concern to the geothermal energy in Lebanon and studies on this respect are still rare except brief mentioning the existence of this source in many articles [2,4,5]. Meanwhile, there are many observations of natural hot water in different localities on the Lebanese territory, likewise many other observations on the neighboring countries, such as in Syria and Jordan. However, no detailed investigation has been done to interpret their hydrological regime, and then to induce how they can be exploited.

There is no hydrological or geophysical investigations applied in Lebanon in order to verify the existence of geothermal water. The known observations imply spontaneously (naturally) evidenced phenomenon of hot water discharge either in springs or water wells. Many of the known hot water (and sometimes warm water) discharges were existed in places where igneous rocks (almost basalt and tuff) are exposed, but this is not always the case and some of them occur in the proximity of basaltic rocks too.

The major objective of this study is to characterize the existing geothermal water sources, which are represented by hot and warm water, with a special emphasis on the geological and hydrological setting where they exist. This will help identifying the major geologic elements governing the flow regime of geothermal water, thus identifying their hydrologic controls, which help indicating the existence of new geothermal sources in different places in Lebanon. This in turn motivates applying further studies with detailed investigation, which may lead to create a strategic plan for geothermal water exploitation in Lebanon.

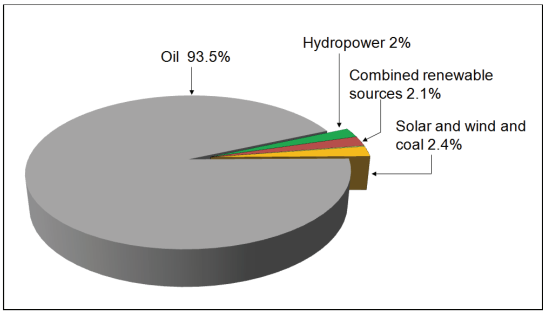

Figure 1. Primary energy supply in Lebanon in 2003 (adapted from ALMEE, 2005 [6]).

2. Indicators of Geothermal Water

Indicators of geothermal water sources in Lebanon imply both surface water and groundwater in different localities and at various levels on/or in the proximity of the basalt rock exposures. The identified sources were indicated by inhabitants, as well as they depend on mentions in previous studies. They can be attributed, in a broad sense, to:

2.1. Springs

In Akkar region, north Lebanon along the Syrian border where large basaltic rock plateau exposed (**Figure 2**), there are several observations for hot/or warm water from springs and seepages at different localities. Many of them show low discharge, which is almost less than 1 *l*/sec; therefore, most of these springs and seeps were dried as a result of overexploitation of groundwater, and also due to the ignorance of these sources by local community. Yet, one these springs remain and called “AinEsamak” spring. However, it is totally ignored and has not been properly utilized. Filed testing shows that the average temperature of this spring ranges between 50-65°C over various time periods.

2.2. Off-Shore Springs

The hydrologic phenomenon of hot and warm water is not limited to the terrestrial environment, but also it extends to the marine environment where some off-shore hot springs were identified by fishermen along the Lebanese coastal zone. These off-shore springs were identified at three sites, one along the southern coast beside city of Tyre (33°15'33" & 35°11'32"), and the other two in the north, adjacent to A’abdeh (34°31'37" & 35°59'07") and Chekka (34°19'24" & 35°43'21") regions (**Figure 2**). The first one (near Tyre) occurs as thermal vents in sea floor at a distance of about 300 m from the coast and at a depth of about 30 m. These vents were distributed on an area of about 800 m. In addition other smaller vents in the seafloor were observed by fishermen. However, the

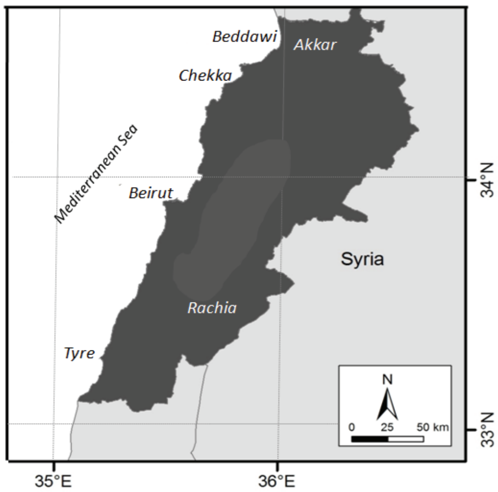

Figure 2. Map of Lebanon showing the sites of known geothermal water.

actual temperatures were not estimated.

The other two were springs were detected during an airborne Thermal Infrared survey when they appear as dissipated clusters of small bubbles (few centimeters in diameter) at a distance from the coast [7]). The temperature of these clusters was about 38°C while the surrounding temperature of water was about 26°C.

2.3. Groundwater

Hot and warm groundwater has been noticed in several drilled wells in Lebanon. This is well pronounced in wells dug into/or near hard and fractured basaltic rocks and some of them were found in the carbonate rocks (*i.e.* dolomite and limestone). However, the latter are almost occur with lower temperature than those in basalt, and the heat was decreased after pumping in many of these wells, which also showed temperate steams, injected along wells' tubes.

This phenomenon has been witnessed in Akkar region in the north as well as in Sohmor and Kaoukaba and El-Ghajar in south (**Figure 2**). Whereas, the most known well was drilled in Akkar in 1970s to a depth of approximately 550 m in the fractured basalts, thus water was injected due to the high piezometric pressure to about 30 above ground. The measured temperature of water was 70°C and it contained high content of sulfur [2].

3. Materials and Method

Based on the criteria that volcanic rocks are the major source of heat to result geothermal water, thus studying the geology of these rocks must be primarily considered in order to induce the relationship between rock structures and lithology with respect to hot water. Hence, the rock succession of Lebanon shows three principal intervening media of basaltic irruption among different sedimentary stratum. These are in the Middle Jurassic, between Late Jurassic and Early Cretaceous as well as in the Pliocene age [8]. Even though, basalt is the major igneous rock type in these levels, yet each of them has different mineralogical characteristics and even their vertical delineation and geographic distribution have various aspects and dimensions.

From a geological point of view, the igneous rocks which are related to relatively recent volcanic eruptions are most considered for the geothermal water sources, since their activity is supposed to be still existing [5]. This is well evidenced since all the existing geothermal water was in/or nearby the Pliocene basalt. Therefore, in the case of Lebanon, Pliocene rock exposures are utmost important to investigate the geothermal water, and for this reason they were tackled in this study.

In accordance with the objective of the study; however, three principal steps were followed:

1) Identifying the geographic distribution of basalt exposures

2) Filed survey and geochemical analysis whenever it was accessible

3) Identifying the hydrological controls for geothermal water.

Identifying the location of geothermal water sources, with respect to the geological formations and rock structures, was the principal task to be done. For this purpose, geological maps (1:50.000 scale) obtained by Dubertret [9] were utilized. Hence, geological field measures were taken (e.g. bedding planes inclination, strata superposition, lithological characteristics, etc) and thus lithological cross-sections and illustrations of rock successions were applied whenever it was needed. This was accompanied with filed investigation to assure the reliability of information on the known geothermal water sources, whether in terrestrial and marine springs as well as for geothermal water in the observed wells. Therefore, direct measurements for the temperature were taken. Consequently, sampling procedures were carried out whenever it was accessible in several sources for further geochemical analysis on the selected sources.

The identified sources were diagnosed in order to understand the geologic setting where they exist, and thus to induce any relationship with the local hydrology. In the light of this scope, maps of rock fractures were also used to figure out the mechanism of water heating and flow regime. For this purpose satellite images, such as Aster images with 15 m resolution (**Figure 3**), were utilized since they are capable to lithologies and fractures properly.

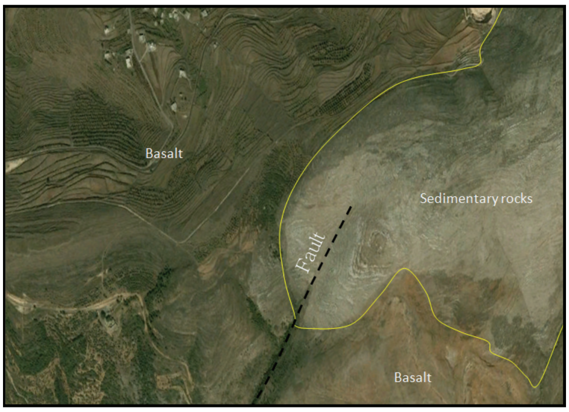

Figure 3. Identification of basalts from Aster images.

4. Results

4.1. Geographic Distribution of Basalt

The geographic distribution of basalts was identified primarily from the available geologic maps as well as they were checked in a field survey, which was carried out on different localities around the basaltic exposures. Thus, basalts with tuffaceous materials of the Pliocene were attributed to four major domains where they are widely spread. They exist in the regions of: Akkar, Hinayder, Kaoukaba and El-Ghajar (**Figure 4**). Since the study concerns with geothermal water sources; however, these domains were described as *geothermal domains*. These domains were investigated using the available geological maps in combination with filed verification to selected sites on the basaltic exposures, thus the major specifications of these domains were summarized (**Table 1**).

The geographic distribution of basalt exposures in these domains can be attributed mainly to the volcanic eruptions along lava veins, dikes and faults, in addition to local fracture systems. Their thickness and spatial extent at different localities and levels indicates the existence of volcanic activity in the Pliocene age (< 2 million years), which points out to the probability of further lava veins and similar geothermal water in other localities in the region.

4.2. Geochemistry of Geothermal Water

The topic on geothermal water in Lebanon is still at the reconnaissance stage, and concerns are not given to induce a potential use of this source. Hence, there is no any existing exploitation procedure of geothermal water. For this reason, geochemical sampling was not properly accessible to apply detailed investigation, such as deep sampling from wells to measure the geothermal gradient and other geochemical properties. Therefore, the geochemistry in this study was carried out depending on the accessibility

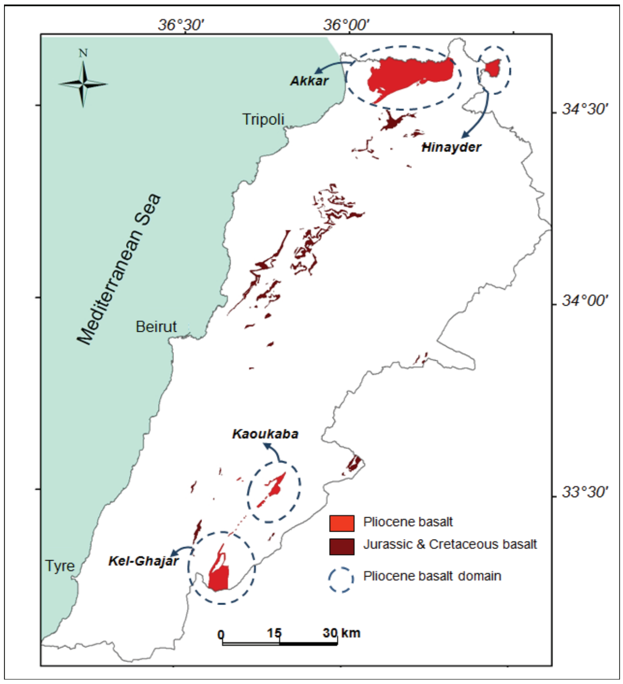

Figure 4. Distribution of basalts in Lebanon.

of water sampling; in particular it was applied to Ain-Esamak spring in Akkar, the off-shore sources in Chekka region and to water well in Koukaba region. Thus, measures were obtained on temperature, pH and salinity (TDS). Results show high carbonate and sulphate contents as well as remarkable pH and temperature (**Table 2**).

According to Bahati *et al.* [10], the geothermal fluids are characterized by high carbonate and sulphate constants and salinity of 19000 to 28000 mg/kg total dissolved solids.

4.3. Hydrology of Geothermal Water

In order to diagnose the hydrology of geothermal water, geological controls (e.g. fractures, veins, rock bed inclination, etc) must be primarily identified. This will help recognizing the mechanism of heating and flow regime of hot water, as well as proposing new geothermal sources. This was applied, in particular, to characterize the stratification of different lithologies and their contact with basalt rock masses, as well as in the basalt rocks themselves. In addition, structure systems were investigated to induce any existing hydrologic correlation.

In this respect, the four geothermal domains were studied and their geologic and hydrologic characteristics were determined. For this scope, filed survey was carried out, thus illustrations and cross sections were established.

In general, the geologic setting of the existing Pliocene basalts in Lebanon constitutes a volcanic lava flow regime.

Table 1. Major basalt domains in Lebanon and their specifications.

Geothermal domain	Coordinates*		Area† (km^2)	Average altitude (*m.a.sl*)	Basalt characteristics
	Latitude	Longitude			
Akkar	34°35'15"	36°08'55"	135	400-450	- Massive basaltic plateau dominant with fracture systems, - Syenite and tuff occur in different localities and at different levels - Fluid inclusions appear as internal and external vascular pits, - Rose-basalt and calcite veins are common.
Hinayder	34°36'50"	36°25'50"	24	500-550	- Basaltic, syenite and tuff occur at various levels, - Surficila fluid inclusions are common, - Laval flow is featuring in several sites.
Kaoukaba	33°23'40"	35°38'50"	17	550-600	- Block basaltic lava with fumaroles - Fracture systems, mainly jointing is dominant
El-Ghajar	33°16'20"	35°37'30"	33	300-325	- Massive and boulder basalts, - Vertical joint and fracture systems are well developed, - Calcite and iron veins exist, - Empty vascular cylindrical veins occur.

*Coordinates in the mid-point area; †Area within Lebanon.

Table 2. Major geochemical measures of selected geothermal water in Lebanon.

Thermal source	Temperature	TDS	pH
Ain-Esamak	65 °C	21000 mg/kg	8.3
Chekka off-shore sources	38 °C	18500 mg/kg	7.7
Koukaba region well	35 °C	16000 mg/kg	7.4

Thus, four interrelations were identified as follows:

- Occurrence of massive basalt plateaus (e.g. Akkar, Hinayder and El-Ghajar domains)
- Lava flow widely erupted among the carbonate rocks of the Cenomanian limestone rock formation (e.g. Akkar and Hinayder domains)
- Lava flow erupted along the Cenomanian and Jurassic carbonates (e.g. El-Ghajar domain)
- Lava flow erupted among or Cenomanian and related laying formations (e.g. Kaoukaba domain).

Therefore, the internal heat affects the groundwater and results geothermal water following two mechanisms:

- Heating within the basalt rock masses, which are characterized by intensive fracture systems (*i.e.* recharge zone), thus high permeability and porosity occur. The percolated (recharged) water into fractures was subjected to heat transfer from deep molten materials (**Figure 5(a)**). This might not be occurred unless the magma is shallow enough to heat directly the basalt.
- Contact heating between the basalt rock masses and the adjacent carbonate rocks, which are almost of fractured and karstified limestone and dolomite aquifers (**Figure 5(b)**).

Accordingly, the existence of geothermal seepages and springs on terrain surface is attributed principally to the existing fault and fissure systems (**Figure 5(b)**), such as the case of the NE-SW trending faults between Bire and Mantara in Akkar region along which the geothermal source of Ain Esamak is located. There is also a similar fault that trends in the NE-SW direction and intersect along Er-Rafid and Kfer Mishka in Kaoukaba region. These faults compose geothermal fracture zones, which is a widely hydrologic phenomenon worldwide, likewise those occur in Turkey and having similar characteristics as Lebanon [11].

Some of the intersecting faults between the basalt and the carbonate rocks have considerable length that exceeds several tens of kilometers and reach the sea floor, as indicated from satellite images [12]. This in turn interprets the existence of geothermal water in the marine environment facing A'abdeh, Chekka and Tyre.

5. Conclusions and Discussions

Energy sources are not usually occurred spontaneously on terrain surface to indicating their existence, but they usually be discovered everywhere by human by applying several methods of investigation. Hence, looking for alternative energy sources must be considered and given attention as much as the current usable sources. This must be applied to Lebanon the country with a great need to have alternative energy sources, notably in the light of

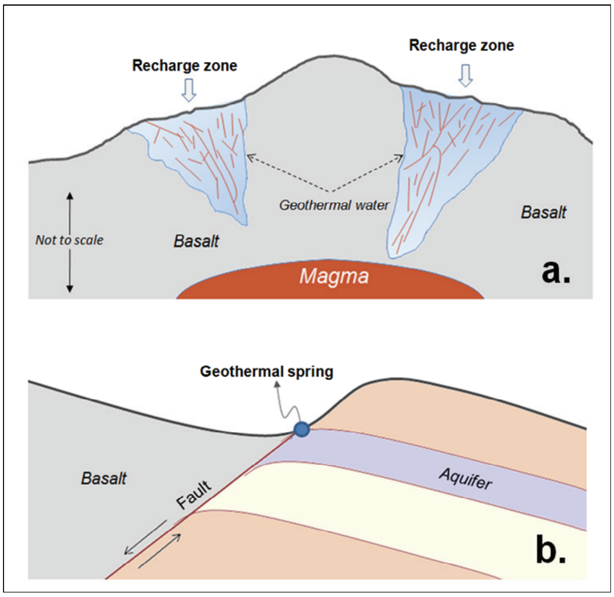

Figure 5. Schematic figures showing various hydrology of geothermal water source.

the existing physical and anthropogenic factors. This can be achieved if strategic plans for natural resources assessment are applied.

A surveillance and research studies, such as the current study, are utmost important. In Lebanon, other than hydro-power, wind and solar energy which are being limitedly utilized as well as the currently discussed oil exploration; however, geothermal energy must be considered, especially by the governmental sectors.

There are many indicators on the geothermal water sources in Lebanon, and they occur in various hydrologic aspects, which were tackled in this study. Yet, there is no detailed information on these sources. This study is an empirical attempt to characterize the existing sources and to put the first hand information on the geologic and hydrologic setting of the geothermal water in Lebanon. It discusses the mechanism of groundwater heating in order to yield geothermal water.

Based on the hydrologic controls in this study, it is obvious that geothermal groundwater in Lebanon is an existing source. It is also evidenced and anticipated to be existed on other sites where the Pliocene basalts are located with similar hydrologic properties. Therefore, the potential localities for geothermal water in Lebanon can be reached by drilling a number of wells on/near the basalt rock masses considering the following hydrological elements:

1) Fault alignments are potential sites for geothermal water, in particular along fault contacts between basalt masses and sedimentary rock sequences. This can be applied to the three trending faults mentioned previously in Akkar, Kaoukaba and El-Ghajar regions.

2) Fracture zones, and more certainly fissure systems, are also promising sites for geothermal water, but only those fissures occurred within the Pliocene basalt body masses and not the sedimentary ones.

3) Deep sedimentary groundwater basins (*i.e.* aquiferous rock formations) that are located in a close proximity to Pliocene basalts are also potential for geothermal water sources, but a number of hydrogeological elements must be taken into account (e.g. hydraulic gradient, strata inclination, etc).

In addition, the existing geothermal sources must be reinvestigated and then plans for exploitation must be put. Such as the Ain Esamak spring, which must be rehabilitated, as well as all geothermal seeps and hot/warm water appears in wells must be investigated in depth. Moreover, the hydrologic conduits that transporting hot water to the sea should be also delineated in order to determine their sources on-land.

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An Analytical Optimal Strategy of the Forest Asset Dynamic Management under Stochastic Timber Price and Growth: A Portfolio Approach

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ABSTRACT

Considering the valuation of forest stands based on revenue from wood sales, concession policy (*such as carbon subsidies*) *and associated costs, the paper focuses on the stochastic control model to study the forest asset dynamic management. The key contribution is to find the optimal dynamic strategy about harvesting quantity in the continual and multiple periods in conditions of stochastic commodity price and timber growth by using portfolio approach. Finally, an analytical optimal strategy is obtained to analyze the quantification relations through which some important conclusions about the optimal forest management can be drawn.*

Keywords: *Forest Management, Analytical, Stochastic Price and Growth, Portfolio, Carbon Subsidies*

1. Introduction

Forest ecosystem harbors a large potential for carbon sequestration and biomass production. When the public good benefits of carbon sequestration are considered, the cash flows from forest management include not only timber value but also carbon subsidies. It is necessary to study how the carbon credit payment influences the decisions of forest harvesting.

Graeme Guthrie and Dinesh Kumareswaran [1] considered the effect of carbon credit payment schemes on forest owners' harvest decisions by using a real options model. They studied two possible payment schemes: one where the government rents the carbon sink, in which case the carbon credit payment is proportional to the current carbon stock and another where the government buys the carbon sink, in which case the carbon credit payment will be proportional to the change in the carbon. They referred to rental scheme as the tree-based carbon credit payment scheme but did not give the detail of contrast.

According to this classification, we found an analytical optimal dynamic strategy about harvesting quantity in conditions of stochastic commodity price and timber growth under the buying scheme by using portfolio approach [2]. In this paper, we will focus on the rental scheme to found the strategy about harvesting quantity and compare with the tow results to draw some conclusions about the selection of carbon subsidies schemes.

The paper is organized as follows. A portfolio model, including carbon sequestration under stochastic wood prices and growth, is introduced in Section 2. In Section 3 we solve the model and obtain the analytical optimal strategy of the forest asset dynamic management by applying stochastic control method in portfolio field. Finally, Section 4 contains some conclusions.

2. The Stochastic Control Model

2.1. The Stochastic Prices

Under stochastic prices, if the harvest is delayed until the next period, the owner will face uncertainty over whether prices will be higher or lower than the current period. According to the geometric Brownian motion, suppose the price of timber, P (\$/m^3), characterized by the following stochastic differential equation:

$$dP = \alpha P dt + \sigma_1 P d\omega_1, \tag{1}$$

where both the expected percentage growth rate α (drift term) and the volatility coefficient σ_1 are exogenously given positive constants and ω_1 is Brownian motion, t is the current time [3-5].

2.2. The Stochastic Growth

Define I (m^3) as inventory of timber (or biomass volume), I_{t+1} and I_t as the stocking levels at age of t + 1 and t, $q(P, I, t)$ as the control variable (the quantity of cutting) of the time t which is depended on the market price P and stocking level I, $g(t, I_t - q(P, I, t))$ as the timber growth function with I and q. The relationship of all these variables follows:

$$I_{t+1} - I_t = g(t, I_t - q(P, I, t)) - q(P, I, t), \tag{2}$$

If we assume that growth is governed by the stochastic process, the timber volume I satisfies the stochastic differential equation:

$$\begin{aligned} dI &= \mu(I - q)dt + \sigma_2 d\omega_2 - qdt \\ &= [\mu I - (1+\mu)q]dt + \sigma_2 d\omega_2, \end{aligned} \tag{3}$$

The inventory growth rate, $[\mu I - (1+\mu)q]$, depends on the cutting rate policy $q(P, I, t)$ and can be either negative or positive. The parameter μ corresponds to the inventory growth rate as a percentage of the residual inventory. The coefficient σ_2 is the volatility parameter representing the uncertainty over the inventory growth rate and ω_2 is Brownian motion [6-8].

Under these assumptions, the forest owner's optimal problem is to determine the control strategies $q^*(P, I, t)$ at the different age t for the maximization of a so-called value function V during the period $t \in (t_0, T)$, where t_0 is the age of the mature forest that is permitted to be cut, and can be noted as *0* for simplification, and T is the final time when forest is harvested in one time or the expiration year of the forest lease (T_e), $T = \min\{T_e, t(q_t \geq I_t)\}$. We assume that management decisions can be implemented only at fixed time points $t_0, t_1 ......, t_n = T$, e.g., only on a yearly basis, and action payments are also received at these specified time points only.

2.3. The Value Function

Under the optimality portfolio principle, the value of forest is composed of log market value and standing forest value, and the value function V about time t can be decomposed into the sum of the immediate profit π and the expected discounted continuation value $E(V)$:

$$\begin{aligned} V(P, I, t) &= \max_{q^* \in [0, \min(I, \bar{q})]} e^{-\rho t}\{\int_0^T \pi(P, q, t)dt + \\ &E[V(P_{t+\Delta t}, I_{t+\Delta t}, t+\Delta t) | P_t, I_t]\}. \end{aligned} \tag{4}$$

where $\bar{q}$ is the maximum annual cutting permission of policy, ρ is the resource manager's risk-free discount rate, and the immediate profit π is composed of amenity value of standing forest (A) and log value (B) minus the operating costs of harvesting and management (C) (including the appropriate amount of carbon credits that must be purchased back once the harvest is performed).

Especially, if we consider the payments arising from carbon sequestration and suppose that carbon payments are received from any increment in standing volume, the CO_2 prices is a constant number P_C, and the parameter γ (a conversion factor) states how many tons of CO_2 are sequestered in 1 m^3 of wood, the value of standing forest will be as follows:

$$A(P_C, \Delta I) = \gamma P_C (I - q) \tag{5}$$

The log value is

$$B(\tau, P, q) = (1-\tau)Pq, \tag{6}$$

where τ corresponds to the tax rate of revenues.

The cost function is given by the quadratic equation

$$C(q) = a_0 + a_1 q + a_2 q^2, \tag{7}$$

where a_0 is the fixed cost, a_1 is the variable cost, and a_2 is the quadratic term reflecting increasing marginal cost. The quadratic functional form is not critical, and is chosen solely for its algebraic simplicity.

Then, the cash flow from forest [4,8,9] is

$$\begin{aligned} \pi(P, q, t) &= A(P_C, \Delta I) + B(\tau, P, q) - C(q) \\ &= \gamma P_C (I - q) + (1-\tau)Pq - (a_0 + a_1 q + a_2 q^2), \end{aligned} \tag{8}$$

So, the value function under the above assumptions follows the equation:

$$\begin{aligned} &V(P, I, t) = \\ &\max_{q^* \in [0, \min(I, \bar{q})]} e^{-\rho t}\{\int_0^T [\gamma P_C (I - q) + (1-\tau)Pq - \\ &(a_0 + a_1 q + a_2 q^2)]dt + E[V(P_{t+\Delta t}, I_{t+\Delta t}, t+\Delta t) | P_t, I_t]\}. \end{aligned} \tag{9}$$

3. An Analytical Solution

According to the above model, the classical tools of stochastic optimal control and maximum principle [10,11] lead to the following Hamilton-Jacobi-Bellman (HJB) equation:

$$\begin{aligned} \rho V &= V_t + [\mu I - (1+\mu)q]V_I + \alpha P V_P + \\ &\frac{1}{2}\sigma_2^2 P^2 V_{PP} + \frac{1}{2}\sigma_1^2 V_{II} + \sigma_1 \sigma_2 P V_{PI} + \\ &e^{-\rho t}\{(\gamma P_C I - a_0) - [\gamma P_C - (1-\tau)P + a_1]q - a_2 q^2\}, \end{aligned} \tag{10}$$

We denote it simply as:

$$\begin{aligned} \rho V &= V_t + [\mu I - (1+\mu)q]V_I + \alpha P V_P + \\ &\frac{1}{2}\sigma_2^2 P^2 V_{PP} + \frac{1}{2}\sigma_1^2 V_{II} + \sigma_1 \sigma_2 P V_{PI} + \\ &e^{-\rho t}(\lambda_0 - \lambda_1 q - \lambda_2 q^2), \end{aligned} \tag{11}$$

where

$$\begin{aligned} \lambda_0 &= \gamma P_C I - a_0, \\ \lambda_1 &= \gamma P_C - (1-\tau)P + a_1, \\ \lambda_2 &= a_2, \end{aligned} \tag{12}$$

From (11), the optimal policy q^* satisfies

$$q^* = -\frac{1}{2\lambda_2}[(1+\mu)V_I e^{\rho t} + \lambda_1], \quad (13)$$

Putting (13) in (11), we obtain another partial differential equation:

$$\rho V = V_t + \mu I V_I + \alpha P V_P + \frac{1}{2}\sigma_2^2 P^2 V_{PP} + \frac{1}{2}\sigma_1^2 V_{II} + \sigma_1\sigma_2 P V_{PI} + \lambda_0 e^{-\rho t} + \frac{(1+\mu)^2}{4\lambda_2} e^{\rho t} V_I^2 + \frac{\lambda_1(1+\mu)}{2\lambda_2} V_I + \frac{\lambda_1^2}{4\lambda_2} e^{-\rho t}. \quad (14)$$

We try to find a solution to (14) in the following way:

$$V = e^{-\rho t} f(P, I), \quad (15)$$

Introducing this in (14), we obtain:

$$2\rho f = \mu I f_I + \alpha P f_P + \frac{1}{2}\sigma_2^2 P^2 f_{PP} + \frac{1}{2}\sigma_1^2 f_{II} + \sigma_1\sigma_2 P f_{PI} + \frac{(1+\mu)^2}{4\lambda_2} f_I^2 + \frac{\lambda_1(1+\mu)}{2\lambda_2} f_I + \frac{\lambda_1^2}{4\lambda_2} + \lambda_0, \quad (16)$$

Namely, as that:

$$2\rho f = \mu I f_I + \frac{1}{2}\sigma_1^2 f_{II} + \gamma P_C I + \frac{(1+\mu)^2}{4a_2} f_I^2 + \frac{(\gamma P_C + a_1)(1+\mu)}{2a_2} f_I + \sigma_1\sigma_2 P f_{PI} - \frac{(1+\mu)(1-\tau)}{2a_2} P f_I + \alpha P f_P + \frac{1}{2}\sigma_2^2 P^2 f_{PP} + \frac{(1-\tau)^2}{4a_2} P^2 - \frac{(\gamma P_C + a_1)(1-\tau)}{2a_2} P + \frac{2\gamma P_C a_1 + \gamma^2 P_C^2 + a_1^2 - 4a_0 a_2}{4a_2} \quad (17)$$

Decompose $f(P, I)$ as:

$$f = g(I) + h(P), \quad (18)$$

Introducing this in (17), we obtain:

$$\mu I g_I + \frac{1}{2}\sigma_1^2 g_{II} + \frac{(1+\mu)^2}{4a_2} g_I^2 + \frac{(\gamma P_C + a_1)(1+\mu)}{2a_2} g_I + \gamma P_C I - \frac{(1+\mu)(1-\tau)}{2a_2} P g_I - 2\rho h + \alpha P h_P + \frac{1}{2}\sigma_2^2 P^2 h_{PP} + \frac{(1-\tau)^2}{4a_2} P^2 - \frac{(\gamma P_C + a_1)(1-\tau)}{2a_2} P + \frac{2\gamma P_C a_1 + \gamma^2 P_C^2 + a_1^2 - 4a_0 a_2}{4a_2} = 2\rho g. \quad (19)$$

Assume that

$$g(I) = k_1 I + l_1, . h(P) = k_2 P^2 + l_2 P + m_2, \quad (20)$$

Introducing this in (18), we obtain:

$$(-2\rho k_1 + \mu k_1 + \gamma P_C) I + [\frac{(1+\mu)^2}{4a_2} k_1^2 + \frac{[\gamma P_C + a_1](1+\mu)}{2a_2} k_1 - 2\rho l_1] + [\frac{(1-\tau)^2}{4a_2} + \sigma_2^2 k_2 + 2\alpha k_2 - 2\rho k_2] P^2 + [\alpha l_2 - \frac{(1+\mu)(1-\tau)}{2a_2} k_1 - 2\rho l_2 - \frac{[\gamma P_C + a_1](1-\tau)}{2a_2}] P - 2\rho m_2 + \frac{2\gamma P_C a_1 + \gamma^2 P_C^2 + a_1^2 - 4a_0 a_2}{4a_2} = 0, \quad (21)$$

It is not difficult to decide $k_1, l_1, .k_2, l_2, m_2$ by the method of undeterminated coefficients, such as

$$k_1 = \frac{\gamma P_C}{2\rho - \mu}, (2\rho - \mu \neq 0) \quad (22)$$

We are not usually interested in the value function, but rather in the optimal strategy. From (12), (13), (15), (18) and (22), it is given by:

$$q^* = \frac{1}{2a_2}[(1-\tau)P - \frac{2\rho + 1}{2\rho - \mu}\gamma P_C - a_1] \quad (23)$$

4. Conclusions

It is not difficult to draw some conclusions about the quantity of harvesting from (22):

1) The quantity is decided by the log market price (P), the concession value or the carbon price (P_C), the timber growth average speed (μ), the discount rate (ρ), the tax rate (τ), the carbon transform coefficient (γ), and the costs coefficients (a_1 and a_2), but it has nothing with the gross of present forest (I), the fixed cost (a_0), the price volatility (σ_1), and the timber growth volatility (σ_2).

2) It is obvious that the more expensive timber price is and the lower tax rate is, the more trees will be cut down.

3) Normally, two times of the discount rate is larger than the timber growth rate ($2\rho > \mu$), so the more concession value there is, the less trees will be cut down. It means that the forest concession or the carbon credit payment schemes can discourage deforestation. Otherwise, if the timber growth average speed is faster than two times of the discount rate, the owner will harvest more forest to pursuit more wood sales value, with the fast-growing forestry as an example. In another word, only policies such as subsidies from government are not able to satisfy the forest owners' profits. So it is important to improve the management and technology to increase the growth rate of forest.

4) Obviously, the more cost of harvesting, the less

trees will be cut down. But we find that the fixed cost does not influence it. The cost is also can be regarded as the penalty for the destruction.

5) As said above, the harvesting strategy has nothing with the gross of present forest, so the control of the portfolio is suitable for any scope of forest regardless of the amount.

In a word, we believe many more interesting conclusions will be brought under the different assumptions by using the portfolio approach, and welcome more researchers to take part in the field.

5. Acknowledgements

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Effect of Wind Generation System Rating on Transient Dynamic Performance of the Micro-Grid during Islanding Mode

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ABSTRACT

Recently, several types of distributed generations (DGs) are connected together and form a small power system called Micro Grid (MG). This paper developed a complete model which can simulate in details the transient dynamic performance of the MG during and subsequent to islanding process. All MG's components are modeled in detail. The developed model is used to investigate how the transient dynamic performance of the MG will affected by increasing the rating of wind generation system installed in the MG. Two cases are studied; the first case investigates the dynamic performance of the MG equipped with 10 *kW fixed speed wind generation system. The second studied case indicates how the dynamic performance of the MG will be affected if the wind generation system rating increases to* 30 *kW. The results showed that increasing of wind generation rating on the MG causes more voltage drops and more frequency fluctuations due to the fluctuation of wind speed. Increasing voltage drops because wind turbine generator is a squirrel cage induction generator and absorbs more reactive power when the generated active power increases. The frequency fluctuations due to power fluctuations of wind turbine as results of wind speed variations. The results proved that when the MG equipped with large wind generation system, high amount of reactive power must be injected in the system to keep its stability. The developed model was built in Matlab® Simulink® environment.*

Keywords: *MG, Distributed Generators, Wind Power Rating and Dynamic Performance*

1. Introduction

Recent technological developments in micro generation domain, necessity of reducing CO_2 emissions in the electricity generation field, and electricity business restructing are the main factors responsible for the growing interest in the use of micro generation [1,2]. In fact the connection of small generation units—the micro sources (MS), with power rating less than a few tens of kilowatts—to low voltage (LV) networks potentially increases the reliability to final consumers and brings additional benefits for global system operation and planning, namely, regarding investment reduction for future grid reinforcement and expansion [3].

In this context, a MG can be defined as a LV network (e.g. a small urban area, a shopping center, or an industrial park) plus its loads and several small modular generation systems connected to it, providing both power and heat to local loads [combined heat and power (CHP)] [3]. The MG is intended to operate in the following two different operating conditions:

- *Normal Interconnected Mode*: MG is connected to a main grid (distribution network), either being supplied by it or injecting some mount of power into the main system.
- *Emergency Mode*: MG operates autonomously, in a similar way to physical islands, when the disconnection from the upstream distribution network occurs.

The development of MGs can contribute to the reduction of emissions and the mitigation of climate changes. This is because available and currently developing technologies for distributed generation units are based on renewable sources and micro sources that are characterized by very low emissions [4]. The new micro sources technologies (e.g. micro gas turbine, fuel cells, photovoltaic panels and several kinds of wind turbines) used in MG are not suitable for supplying energy to the MG directly

[3]. They have to be interfaced with the MG through an inverter stage. Thus, the use of power electronic interfaces in the MG leads to a series of challenges in the design and operation of the MG [5]. Technical challenges associated with the operation and control of MG are immense. Ensuring stable operation during network disturbances, maintaining stability and power quality in the islanding mode of operation requires the development of sophisticated control strategies for MG's inverters in order to provide stable frequency and voltage in the presence of arbitrarily varying loads. This paper's objective is to demonstrate the transient dynamic performance of the MG during and subsequent to islanding process and how it will affected with increasing the wind power rating installed in the MG.

Reference [6] discusses MG autonomous operation during and subsequent to islanding process but the renewable micro sources not included, also, this reference used PSCAD/EMTDC package for analysis. In references [7] and [8] a control scheme based on droop concepts to operate inverter feeding a standalone AC system is discussed. References [9] and [10] discuss the behavior of distributed generators (DGs) connected to distribution network, however, the dynamics of the primary energy sources has not been considered, not allowing obtaining the full picture of the MG long-term dynamic behavior, which is largely influenced by the micro sources dynamic.

This paper developed a complete model to simulate the dynamic performance of the MG. All MG's components are modeled in details. The developed model is a general and can be used to study any disturbance which may occur in the MG. Effect of increasing wind power rating is investigated. Two cases are studied; the first case is studying the transient dynamic performance of the MG equipped with 10 kW fixed speed wind generation system. The second case is how the dynamic performance of the MG will affect when the wind generation system is increased to 30 kW. The developed model was built in Matlab® Simulink® environment.

To conduct the proposed studies, single line diagram of the studied MG is presented in Section 2. Section 3 gives a brief description of all MG's components developed models. Section 4 presents a description of the complete model with the applied controls. Two studied cases with results and discussions are explained in Section 5. Conclusions are presented in Section 6.

2. Single Line Diagram of the Studied Micro-Grid

Figure 1 shows single line diagram of the studied MG. It consists of 7 buses. Flywheel is connected to bus # 1. Wind generation system is connected to bus # 2. Two

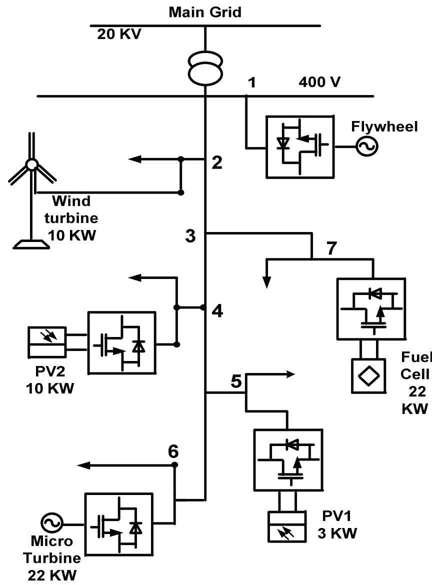

Figure 1. Single line diagram of the studied MG.

photovoltaic panels with rating 10 kW and 3 kW are connected to buses 4 and 5, respectively. Single shaft micro turbine (SSMT) with rating 22 kW is connected to bus # 6. Bus 7 is provided with 22 kW solid oxide fuel cell (SOFC). The values loads and line parameters of the MG are available in reference [11].

3. Description of Microgrid Individual Components Models

3.1. Inverter Models

Inverters play a vital role in the system which interfaces of the micro sources with the AC power system. Two control models of the inverter which used to interface micro sources to the MG are developed. The configuration of the basic inverter interfaced micro sources is shown in **Figure 2**.

The inverter controls both the magnitude and phase angle of its output voltage (V in **Figure 2**). The vector relationship between the inverter voltage (V) and the local MG voltage (E in **Figure 2**) along with the inductor's reactance determines the flow of active and reactive powers from the micro source to the MG [12]. The corresponding mathematical relations for P (active power) and Q (reactive power) magnitudes are given by the following equations:

$$P = \frac{VE}{\omega L}\sin(\delta_V - \delta_E) \quad (1)$$

$$Q = \frac{V^2}{\omega L} - \frac{VE}{\omega L}\cos(\delta_V - \delta_E) \quad (2)$$

From Equation (1) and Equation (2), the control of ac-

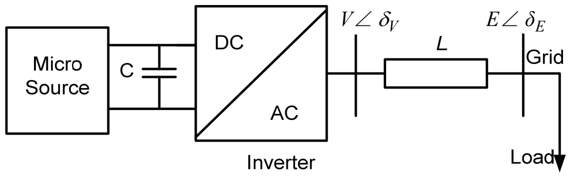

Figure 2. Basic inverter interfaced micro source.

tive and reactive powers flow reduces to the control of power angle and the inverter's voltage level, respectively.

P is the active (real) power (Watts) generated by micro sources (Flywheel, wind generator, fuel cell, micro turbine and photovoltaic panels). Frequency control depends on the amount of active power (P) in the Micro Grid. If P generated by micro sources is higher than P consumed by loads, frequency increase than its nominal value and vice versa.

On the other hand, Q is the reactive power (its unit is Volt Ampere Reactive VAR). The value of the reactive power can be controlled by controlling inverters which interface micro sources with the Micro Grid (MG). Voltage is controlled by controlling amount of reactive power generated in the MG.

3.1.1. Inverter Model with PQ Controller Scheme

The basic structure of inverter *PQ* controller is shown in **Figure 3** [8].

Active and reactive powers can be controlled independently to a good extent, then as shown in **Figure 3**, two Proportional Integral (PI) controllers would suffice to control the flow of active and reactive powers by generating the proper values of voltage magnitude (V) and phase angle (δ_V) based on the instantaneous values of voltages and currents which are measured from local MG voltage (E_{bus}). If the inverter switching details are ignored, the control system will be simplified to the configuration shown in **Figure 4** [12].

Inverter *PQ* model is suitable for interfacing single shaft micro turbine, solid oxide fuel cell and photovoltaic panels. **Figure 5** shows the terminal block diagram of the *PQ* inverter developed model. The input terminals are active and reactive powers produced by the micro source, while the output terminals are the three phase terminals connected to the MG.

3.1.2. Inverter Model with *Vf* Controller

In order to develop a model for voltage-frequency controlled inverter, two control loops are needed. Frequency controller is a proportional integral (PI) controller which is driven by the frequency deviation. As shown in **Figure 6(a)**, frequency of the system can be measured by a phase locked loop (PLL), and in order to get a better performance, a feed-forward controller can be implemented. To

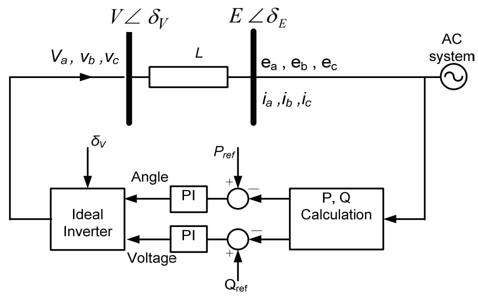

Figure 3. Basic structure of the inverter PQ control scheme.

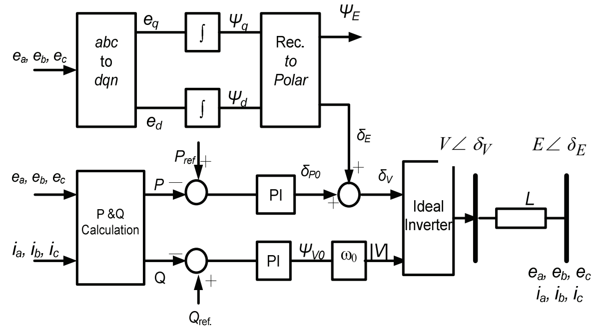

Figure 4. Simplified inverter *PQ* control scheme.

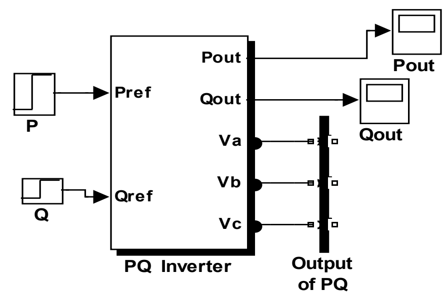

Figure 5. Inverter *PQ* control model.

regulate the voltage, the set point (reference voltage E_{ref}) is compared with the measured voltage (MG voltage E) and a PI controller is responsible to generate the adequate voltage magnitude V as shown in **Figure 6(b)** [12]. *Vf* mode is the model which keep the voltage at constant value and return the frequency to its nominal after disturbance occurring by controlling the amount of the active power injected in the MG. *Vf* inverter is used to interface the flywheel to the MG and represents the reference bus (slack bus) of the MG during and subsequent to islanding occurrence as shown in **Figure 7**.

3.2. Micro Sources Models

Detailed standalone models for micro turbine, fuel cell, wind generation system and photovoltaic panels are developed. Those models are briefly described as follows:

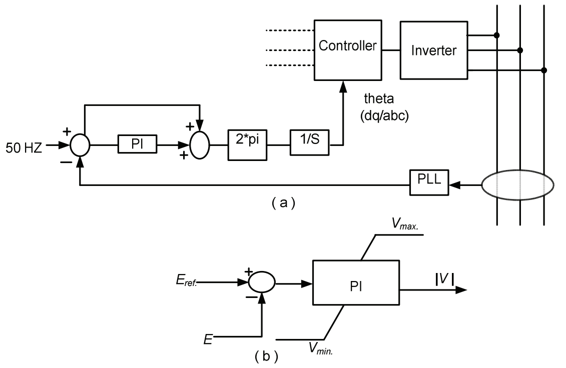

Figure 6. Inverter *Vf* control scheme.

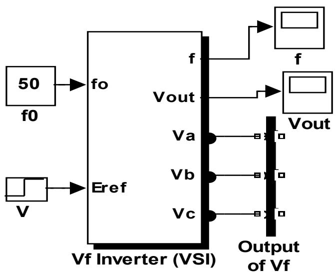

Figure 7. *Vf* controlled inverter.

3.2.1. Single Shaft Micro Turbine Model (SSMT)

References [13-16] describe in details the mathematical model of single shaft and split-shaft micro turbine. The mathematical model is simulated in Matlab® Simulink® environment and the model is shown in **Figure 8(a)**. Input terminal is P_{ref} which represent the desired power. The output terminal is P_e (electrical power output from synchronous generator which coupled with micro turbine). P_e is connected to P input terminal of the *PQ* inverter. Load connected to the synchronous generator is a virtual resistive load because in Matlab® Simulink® the synchronous generator model must always connected to external load.

3.2.2. Solid Oxide Fuel Cell (SOFC) Model

Detailed mathematical model of solid oxide fuel cell (SOFC) is discussed by references [13,14,17]. This model is simulated using Matlab® Simulink® and model block diagram is shown in **Figure 8(b)**. Input terminals are P_{ref} (desired power) and rated voltage of fuel cell (V_{rated}). Output terminal is P_e which represents the electrical power output from fuel cell. This terminal is applied to P input terminal of the *PQ* inverter model.

3.2.3. Wind Generation System Model

Wind generator used in this paper is a squirrel-cage induction generator that directly connected to the MG. Wind turbine model is based on the steady state power characteristic of the turbine. The stiffness of the drive

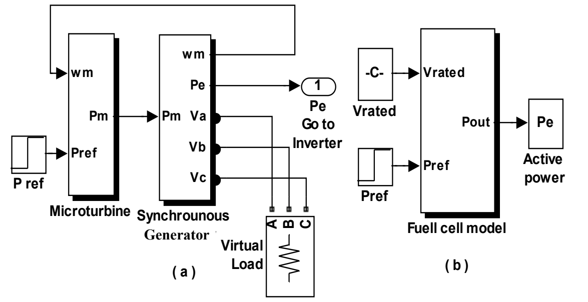

Figure 8. Micro turbine and fuel cell standalone developed models.

train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine [14,18].

The output power of the turbine is given by the following equation:

$$P_m = C_P(\lambda, \beta)\frac{\rho A}{2} v_{wind}^3 \tag{3}$$

where:

P_m: Mechanical output power of the turbine (W).

C_P: Performance coefficient of the turbine.

ρ: Air density (kg/m^3).

v_{wind} : Wind speed (m/s).

λ: Tip speed ratio of the rotor blade tip speed to wind speed.

β: Blade pitch angle (deg.) and

A: Turbine swept area (m^2).

A generic equation is used to model C_P (λ, β). This equation, based on the modeling turbine characteristics of reference [18], is:

$$c_P(\lambda, \beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right)e^{\frac{-c_5}{\lambda_i}} + c_6\lambda \tag{4}$$

$$\text{with: } \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{5}$$

The coefficient C_1 to C_6 are: $C_1 = 0.5176$, $C_2 = 116$, $C_3 = 0.4$, $C_4 = 5$, $C_5 = 21$ and $C_6 = 0.0068$ [18].

For the induction generator, the well-known 4th order *dq* model is used, expressed in the arbitrary reference frame, rotating with an angular velocity ω [19]:

$$u_{sd} = -r_s.i_{sd} - \omega.\psi_{sq} + p\Psi_{sd} \tag{6}$$

$$u_{sq} = -r_s.i_{sq} + \omega.\psi_{sd} + p\psi_{sq} \tag{7}$$

$$u_{rd} = 0 = r_r.i_{rd} - (\omega - \omega_r).\psi_{rq} + p\psi_{rd} \tag{8}$$

$$u_{rq} = 0 = r_r.i_{rq} + (\omega - \omega_r).\psi_{rd} + p\psi_{rq} \tag{9}$$

Where $p = \frac{1}{\omega_0}\frac{d}{dt}$, and ω_0 is the base electrical angular frequency. Generator convention is used for the stator currents. The zero sequence equation is omitted, since the machine stator is connected. The stator and rotor fluxes are related to the currents by:

$$\psi_{sd} = -X_s.i_{sd} + X_m.i_{rd} \quad (10)$$

$$\psi_{sq} = -X_s.i_{sq} + X_m.i_{rq} \quad (11)$$

$$\psi_{rd} = -X_m.i_{sd} + X_r.i_{rd} \quad (12)$$

$$\psi_{rq} = -X_m.i_{sq} + X_r.i_{rq} \quad (13)$$

The electromagnetic torque is given by:

$$T_e = \psi_{qr}.i_{dr} - \psi_{dr}.i_{qr} \quad (14)$$

The wind turbine implemented in this paper is a pitch angle controlled and directly connected to the MG with no power electronic interface. Developed wind generation system model is shown in **Figure 9**. The wind turbine is coupled to a squirrel cage induction generator. The input terminals of the wind turbine are wind speed (m/sec.) and pitch angle of the turbine blades (degree). The output terminal of the wind turbine is mechanical torque (T_m) which applied to the shaft of the induction generator. The terminals of the induction generator are connected directly with the MG. In the two studied cases, the wind speed changes continuously. The values of actual wind speed are available in reference [4].

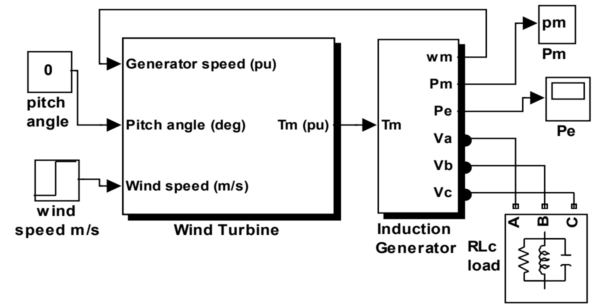

Figure 9. Wind generation system model.

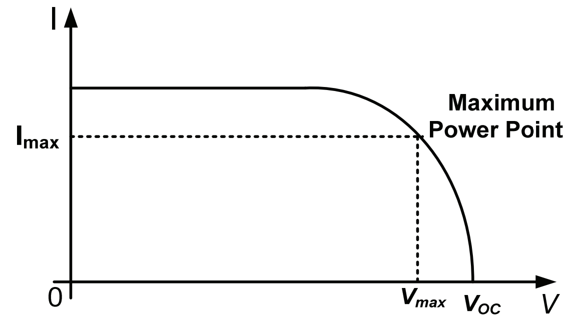

Figure 10. Typical I-V characteristics for a *PV* array.

3.2.4. Photovoltaic Panel Model.

The *PV* array is a grouping of *PV* modules in series and/or in parallel, being a *PV* module a grouping of solar cells in series and/or in parallel. In this study, Maximum Power Point Tracker (MPPT) is used to assure that the *PV* array generates the maximum power for all irradiance and temperature values as shown in **Figure 10**. The whole algorithm for the computation of the maximum power of the PV under certain ambient Temperature (T_a) and Irradiance (G_a) is summarized in the next steps:

- The required parameters are extracted from MG parameters data base (required voltage, current and power).
- The *PV* module's power is computed based on its dependency on Irradiance and cell Temperature as given in Equation (15) [4,14].

$$P_{Max}^{M} = \frac{G_a}{G_{a,o}}[P_{Max,o}^{M} + \mu_{P_{Max}}(T_M - T_{M,o})] \quad (15)$$

where:

$P_{\max}^{M}$: *PV* module maximum power [W]

$P_{\max,o}^{M}$: *PV* module maximum power at standard conditions [W]

$G_{a,o}$: Irradiance at standard conditions [W/m^2]

$\mu_{P_{Max}}$: Maximum power variation with module temperature [W/℃]

T_M : Module temperature [℃]

$T_{M,o}$: Module temperature at standard conditions [℃]

- The working temperature of a *PV* module T_M depends exclusively on the Irradiance (*Ga*) and on the ambient temperature (*Ta*), as shown in Equation (16) [4,14]:

$$T_M = T_a + G_a.\frac{NOCT - 20}{800} \quad (16)$$

where:

T_M : Module temperature [℃]

T_a : Ambient temperature [℃]

G_a : Irradiance [W/m^2]

$NOCT$: Normal cell operating temperature [℃]

- Substituting Equation (16) in Equation (15) and multiplying by the number of modules of the plant, we obtain the maximum power output of the PV plant in Equation (17).

$$P_{Max} = N\frac{G_a}{1000}[P_{Max,o}^{M} + \mu_{P_{Max}}.(T_a + G_a.\frac{NOCT - 20}{800} - 25)] \quad (17)$$

This model is developed in Matlab® Simulink environment and shown in **Figure 11**. Input terminals are Irradiance G_a [W/m^2] and ambient temperature T_a [Kelvin]. In the two studied cases the irradiance is assumed to change continuously and the actual values of irradiance are available in reference [4]. The output terminal is P_{max}, which represents the maximum output power developed by photovoltaic panel. This terminal is applied to the input terminal of the *PQ* inverter.

4. Complete Model Description

The operation of the MG with several *PQ* inverters and a single *Vf* inverter is similar to operation of the MG with synchronous machine as a reference bus (slack bus). *Vf*

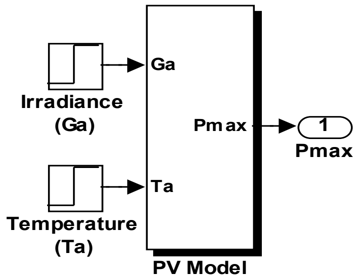

Figure 11. ***PV*** **array developed model.**

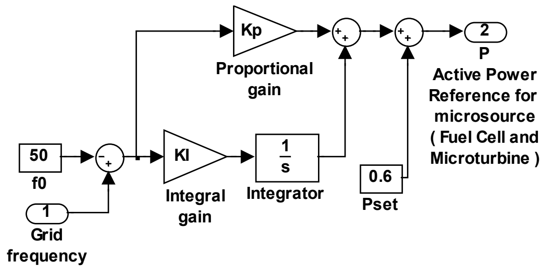

Figure 12. Control of active power of SOFC and micro turbine.

inverter provides the voltage reference for the operation of the *PQ* inverters when the MG is isolated from the main power system. Acting as a voltage source, the *Vf* inverter requires a significant amount of storage capability in the DC link or a prime power source with a very fast response in order to maintain the DC link voltage constant. In other words, the power requested by a *Vf* inverter needs to be available almost instantaneously in the DC link. In fact, this type of behavior actually models the action of the flywheel system. Flywheel was considered to be existing at the DC bus of the *Vf* inverter to provide the required instantaneous power. The *Vf* inverter is responsible for fast load-tracking during transients and for voltage control. During normal operation conditions (stable frequency at nominal value), the output active power of the *Vf* inverter is zero; only reactive power is injected in the MG for voltage control.

4.1. Control of Active Power in Each Micro Source

During islanded (autonomous) operation, when an imbalance between load and local generation occurs, the grid frequency drifts from its nominal value. Storage devices (flywheel) would keep injecting power into the network as long as the frequency differed from the nominal value. Micro turbine and fuel cell are controllable sources which their output power can be controlled. A PI controller (input of this controller is the frequency deviation) acting directly in the primary machine (P_{ref} of fuel cell and micro turbine) allows frequency restoration. After frequency restoration, storage devices will be operating again at the normal operating point (zero active power output). This controller can not apply to wind generation system and photovoltaic panels because those micro sources are uncontrollable sources and their output power depends on weather conditions (wind speed, irradiance and ambient temperature). **Figure 12** shows the PI controller block diagram used to control output power of fuel cell and micro turbine.

4.2. Reactive Power-Voltage Control

Figure 13 describes the adopted voltage control strategy.

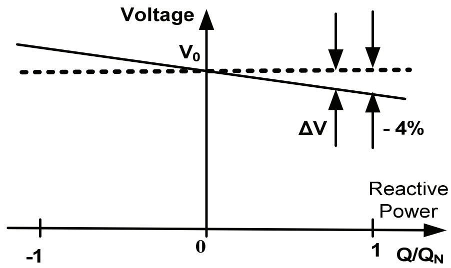

Figure 13. Droop control of the ***Vf*** **inverter terminal voltage.**

Knowing the network characteristics, it is possible to define the maximum voltage droop. To maintain the voltage between acceptable limits, *Vf* inverter connected to the flywheel will adjust the reactive power in the network. It will inject reactive power if the voltage falls under its nominal value and will absorb reactive power if the voltage rises over its nominal value.

4.3. Active Power-Frequency Control

The transition to islanded operation mode and the operation of the MG in islanded mode require micro generation sources to particulate in active power-frequency control, so that the generation can match the load. During this transient period, the participation of the storage devices (flywheel) in system operation is very important, since the system has very low inertia, and some micro sources (micro turbine and fuel cell) have a very slow response to the request of an increase in power generation. As already mentioned, the power necessary to provide appropriate load-following is obtained from storage devices (flywheel). Knowing the network characteristics, it becomes possible to define the maximum frequency droop as shown in **Figure 14**. To maintain the frequency between acceptable limits, *Vf* inverter connected to flywheel will adjust the active power in the network. It will inject active power if the frequency falls below its nominal value and will absorb active power if the frequency rises over its nominal value.

4.4. Complete Model

All micro sources developed models, all inverters developed

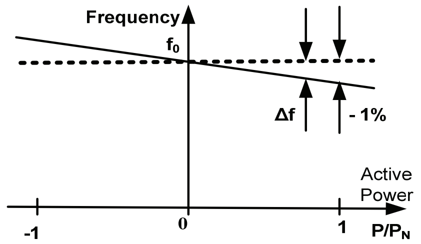

Figure 14. Frequency droop control *Vf* inverter.

models and the control strategies described in the previous sections are collected in one complete model. This model is general and can be used to describe any disturbance may be occur in the MG.

5. Results and Discussions

In the simulation platform, the two PV panels, the SOFC and the single shaft micro turbine are interfaced to MG through *PQ* inverters. As the inverter control is quite fast and precise, it is possible to neglect the DC link voltage fluctuations; if losses are also neglected, the output active power of a *PQ* inverter is equal to the output power of the associated micro source. Flywheel is connected to *Vf* inverter.

Case 1: MG *Dynamic Performance Equipped with* 10 *kW Fixed Speed Wind Generation System.*

In this case, amount of active power and reactive power generated from micro sources are adjusted to force MG imports 13 kW and 16 kVAr from the main grid. Disconnection of the upstream main grid was simulated at t = 70 seconds. The simulation results were presented for the main electrical quantities (frequency, voltages, active and reactive powers).

From the previous figures (**Figures 15-18**), the sequence of the events can be interpreted as follows:

- Before islanding occurrence, MG operates at its steady state and imports active and reactive powers from the main grid. Also, the frequency is at its nominal value (50Hz).
- Islanding occurred at t = 70 seconds; the active power provided by main grid is lost which led to decrease in the MG frequency (49.78 Hz) as shown in **Figure 15**. Also, losing of some reactive power which was supplied by main grid forced the voltages to drop to about 97% of their nominal values as shown in **Figure 16.**
- The difference between load powers (active and reactive) and micro sources generated powers (active and reactive) must be compensated by *Vf* inverter connected to the flywheel as shown in **Figure 17**.
- Due to frequency deviation, PI controllers connected to SOFC and SSMT increases the reference powers of those micro sources. The output powers of SOFC and SSMT begin to increase and help frequency restoration

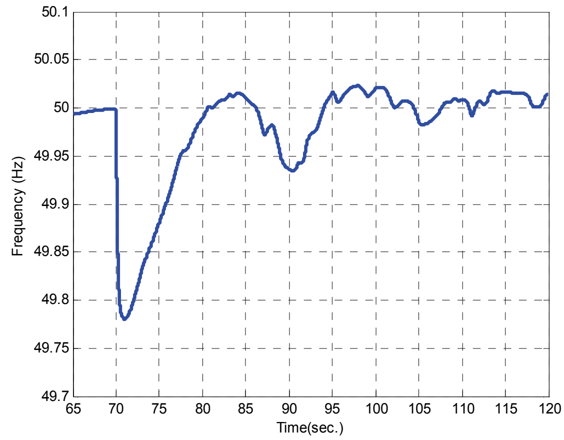

Figure 15. MG frequency before and subsequent islanding.

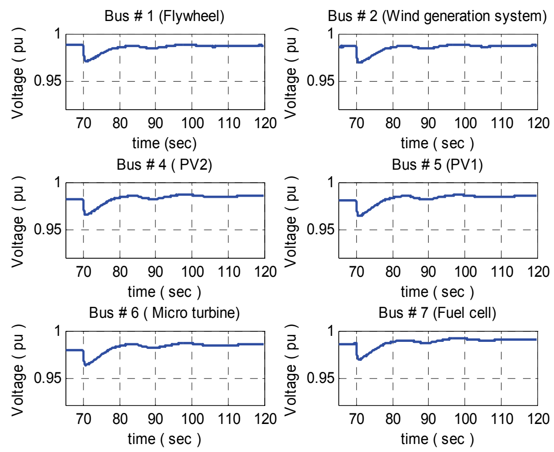

Figure 16. Voltages at all micro sources buses.

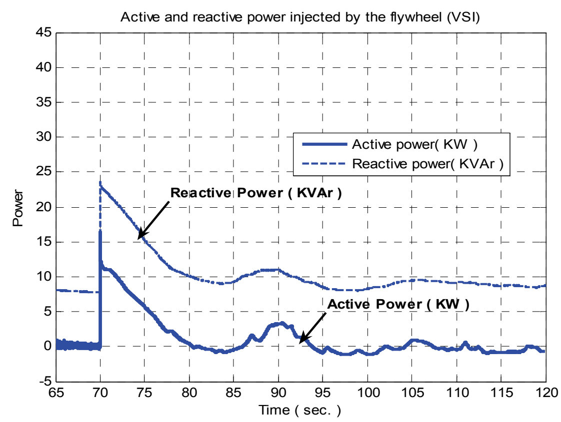

Figure 17. Flywheel (*Vf* inverter) active and reactive powers.

as shown in **Figure 18**.

- Due to wind speed fluctuations, the power generated by wind generator (Squirrel cage induction generator) fluctuates which led to frequency fluctuations. Also, the reactive power absorbed by wind generator (depends

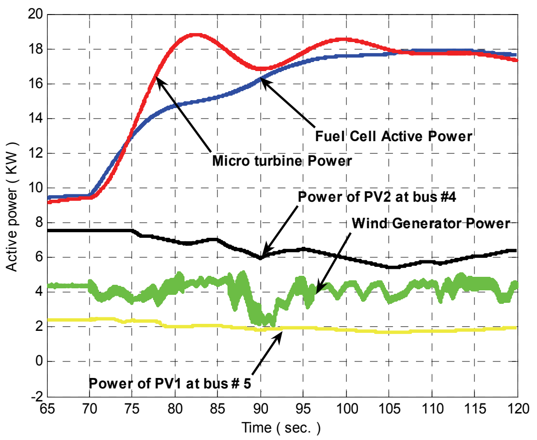

Figure 18. SOFC, SSMT, wind generator and photovoltaic panels generated active powers.

on the amount of generated active power) fluctuates which led to small flicker in voltage. The fluctuations on frequency and voltages are small because the wind generation system has small rating. The variation of photovoltaic panels' output powers is small, because the irradiance and temperature variation is less than the fluctuation of wind speed.

- Due to small rating of wind generation system, amount of reactive power injected in the MG by flywheel to keep the voltage with acceptable limits is small (less than 25 kVAr).
- As shown in **Figure 18**, the response of SSMT is faster than the response of SOFC, so that, SSMT is preferred for system needs fast dynamic response.
- After 30 seconds from islanding occurrence, amount of power produced by micro sources nearly equal to power consumed by the loads and flywheel injected power is nearly equal to zero (only small reactive power injected or absorbed by flywheel *Vf* inverter to compensate renewable sources power fluctuations).

Case 2: *Dynamic Performance of* MG *Equipped with* 30 *kW Fixed Speed Wind Generation System.*

In this case, the MG has the same conditions of the first case except the 10 kW fixed speed wind generation system is replaced by 30 kW fixed speed wind generation system. The disconnection of the upstream main grid was simulated at t = 70 seconds, and the simulation results are shown through the following figures.

From the previous figures (**Figures 19-22**), the following points can be summarized:

- When MG was connected to the main grid, frequency is at its nominal value (50Hz). Difference between loads consumed powers and micro sources generated powers are compensated by the main grid. Active power injected by flywheel settles nearly at zero.
- When islanding occurred at t = 70 seconds, large amount of active and reactive power was lost which led to high drop in frequency (49.74 Hz) and voltage at all buses (94%) as shown in **Figures 19** and **20**, respectively.
- To keep MG stability, flywheel *Vf* inverter must inject high amount of active and reactive powers as shown in **Figure 21**.
- Controllable micro sources (Fuel cell and micro turbine) increase their generated powers to help frequency restoration as shown in **Figure 22**.
- Due to high rating wind generation system, the fluctuations of wind speed causes high fluctuations on output power of the generator which led to high fluctuations on the MG's frequency as shown in **Figure 19**.
- Voltages dropped to about 94% compared with 97% in the first case.
- Amount of reactive power which must be supplied by the *Vf* inverter connected to flywheel is about 45 kVAr compared with 22 kVAr only in the first case.

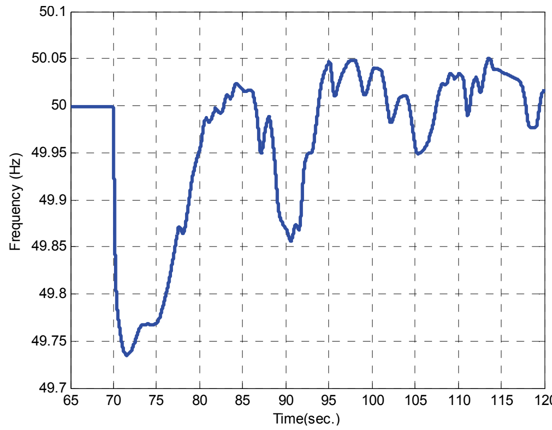

Figure 19. MG frequency.

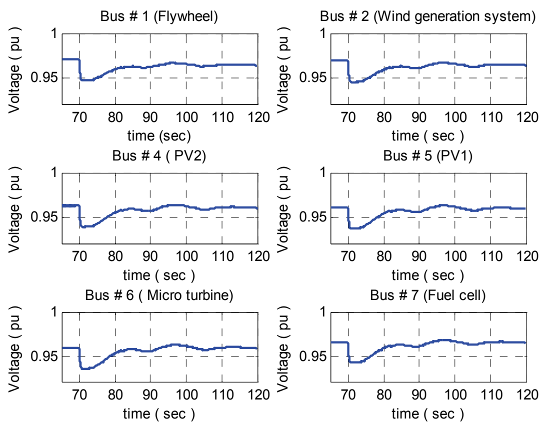

Figure 20. Voltages at all micro sources buses.

6. Conclusions

In this paper, the effect of increasing wind generation system rating in transient dynamic performance of the

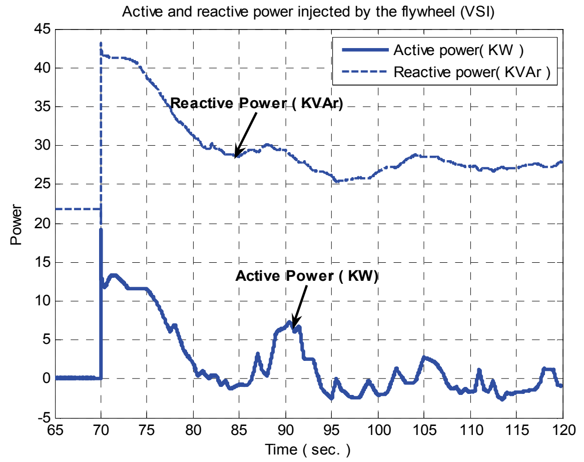

Figure 21. Flywheel (*Vf* inverter) active and reactive powers.

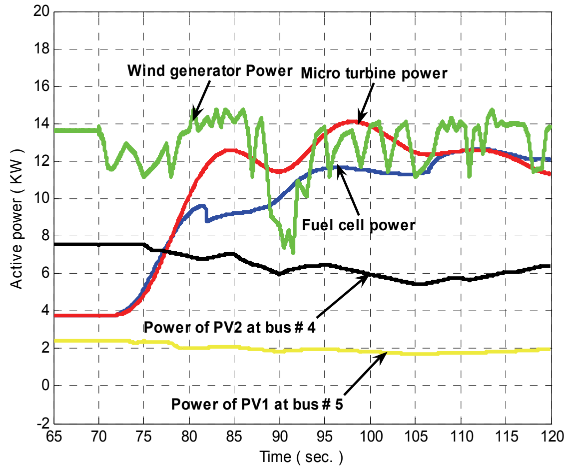

Figure 22. SOFC, SSMT, wind generator and photovoltaic panels generated active powers.

MG during and subsequent to islanding mode is investigated in details. The paper developed a complete model which can describe the dynamic performance of the MG at any disturbance conditions. Two cases are studied, the first case describes the transient dynamic performance of the MG before and subsequent to islanding occurring when the MG is equipped with 10 kW fixed speed wind generation system. The second case describes how the MG dynamic performance will affect if the rating of the fixed speed wind generation system is increased to 30 kW. It is found that, increase the rating of wind generation system required more reactive power which causes high voltage drops at all buses of the MG. Also, fluctuation of wind speed causes more fluctuations in the micro grid frequency in the second case, because the power captured from the wind is proportional to the cube of the wind speed. This paper provides MG's designers with a full picture of the effect of wind generation system rating on dynamic performance of MG and recommends that to prevent the voltage drops with high wind power rating and keep the MG stability, MG should be equipped with adjustable reactive power compensations devices likes static VAR compensator (SVC) or static compensator (STATCOM).

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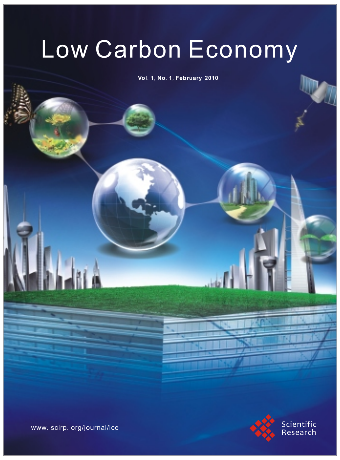

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