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Development of Bond Graph Model for Calculation of Solar Radiation, Application of the Highlands Regions

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***Abstract*—The aim of this work is the estimation of global radiation received on a horizontal surface in any location and at any instant of the day or year in Algeria (highlands regions). In the particular case that interests us and for the development of bond graph models, experimental data of meteorological radiation often lacking. Global radiation can be estimated using bond graph models various relatively accurate and has the advantage of ease of use. New models are proposed to estimate the irradiation. It follows that examples of clear sky days for the Bouzaréah (CDER) site are shown for validation and comparison of experimental results. The results of these models are best supported by experimental data and therefore the accuracy is improved considerably.**

***Keywords*— Bond Graph, Radiation, Solar Flux, Diffuse Flux, Solar Field**

I. Introduction

Renewable energy is an important component of sustainable development because of their close relationship with economic growth, social progress and environmental protection. At the national level, this component is a major focus of the country's energy policy. Indeed, over the past twenty years, Algeria has established the institutional and regulatory framework of energy management in general and has launched a national program in this area focuses on the rational use of energy but also on the promotion of renewable energies. Currently strengthening of this policy becomes increasingly necessary and urgent, given the energy dependence in which our country finds itself and which can be a constraint to economic development. This constraint is likely to increase in the future, with the potential for irreversible increase in international oil prices. At the international level, renewable currently enjoy an environment characterized by globalization, which strengthens the competitiveness requirements and supported by the global awareness on climate change issues and the need to fight against this phenomenon, whose energy consumption is primarily responsible.

The solar field is a set of data describing the evolution of the solar radiation available during a given period. [1] It is used in areas as diverse as agriculture, meteorology, energy applications and public safety. In the operating systems of solar energy, the need for insolation data is of paramount importance both in the design and development of these systems in the evaluation of their performance. The existence of a strong and reliable database is a need for at least the economic survival of plant collection and conversion of solar energy [2]. Although there is a network of stations solar resource assessment, the number of stations is very limited. The number of stations is insufficient and it is for this reason that various models have been proposed to estimate the solar radiation to a local or regional level. These models extend computer codes more complex and sophisticated to simple empirical relationships. The choice of model is dictated by the nature of the data and the desired accuracy [3].

The use of simulation models is practically one of the only ways to solve this problem radiometric data. Beyond the knowledge of the position of the sun in the sky at any time and in any place is required and necessary for the study and the calculation of the intercepted energy source [4].

II. Bond graph approach

A bond graph is a labelled and directed graphical representation of a physical system. The basis of bond graph modelling is power/energy flow in a system. As energy or power flow is the underlying principle for bond graph modelling, there is seam less integration across multiple domains. As a consequence, different domains (such as electrical, thermal.) can be represented in a unified way. The power or the energy flow is represented by a half arrow, which is called the power bond or the energy bond [5], [6].

One of the advantages of bond graph method is that models of various systems belonging to different engineering domains can be expressed using a set of only nine elements: inertial elements (I), capacitive elements (C), resistive elements (R), effort sources (Se) and flow sources (Sf), transformer elements (TF), gyrator elements (GY), 0–junctions (J0) and1–junctions (J1). I, C and R elements are passive elements because they convert the supplied energy into stored or dissipated energy. Se and Sf elements are active elements because they supply power to the system and TF, GY, 0 and 1 are junction elements that serve to connect I, C, R, Se and Sf, and constitute the junction structure of the bond graph model.

Bond graph models are ideally suited for modeling a nonlinear system. A bond graph model does not assume any linearity constraints [7], [8]. The model hides the complexity of nonlinearity from the user of the model. Once the modeler defines the nonlinear relationship in the model, it is the job of the underlying bond graph software to solve the model. The whole process is transparent to the user of the model.

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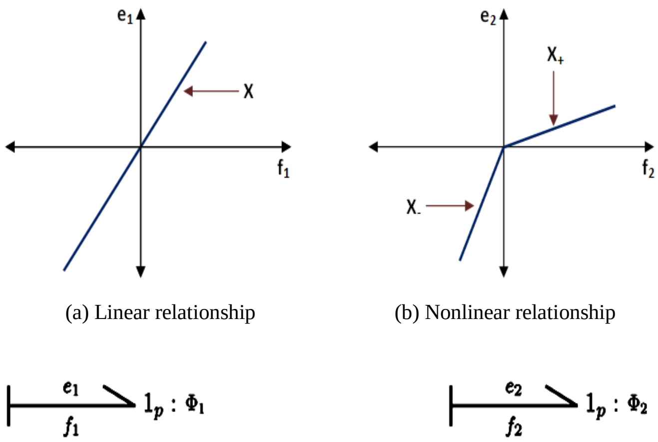
1-port element is the most basic of the bond graph elements. This element has a single port for energy exchange with its environment. There will be a constitutive equation depicting the relationship between the co-variables of the element bond [10].

The only constraint on the constitutive equation is that the energy should be conserved as per the underlying physical law of bond graph modeling. Two different relationships between the co-variables (effort and flow) are depicted graphically in figure (1-a) and (1-b). The bond graph model for this relationship is depicted by 1-port elements in figure (1-c).



(a) Linear relationship (b) Nonlinear relationship

(c) 1-port resistor

Fig. 1 Relationship between flow and effort for 1-port resistor elements

The constitutive relationship for the 1-port resistor elements are given in equations (1) and (2).It can be seen that the model for both linear and nonlinear behavior look-alike, with the constitutive relationship hiding the difference. It is the job of the solver software to simulate the model differently.

$$e_1 = \phi_1 f_1 \quad (1)$$

$$e_2 = \phi_2 (f_2) \quad (2)$$

$$\text{where, } \begin{cases} \phi_1 = X & \text{always} \\ \phi_2 = X_- & \text{if } f_2 < 0 \\ \phi_2 = X_+ & \text{if } f_2 > 0 \end{cases} \quad (3)$$

Bond graph provides a simple approach for modelling complex systems, which allows both a structural and a behavioural system analysis [10].

III. SOLAR BOARD OF ALGERIA

Algeria is a large country with variety in sites that lead to diversity in climate. More than 2.000.000 Km^2 receives yearly a sunshine exposure equivalent to 2500 KWh/m^2.

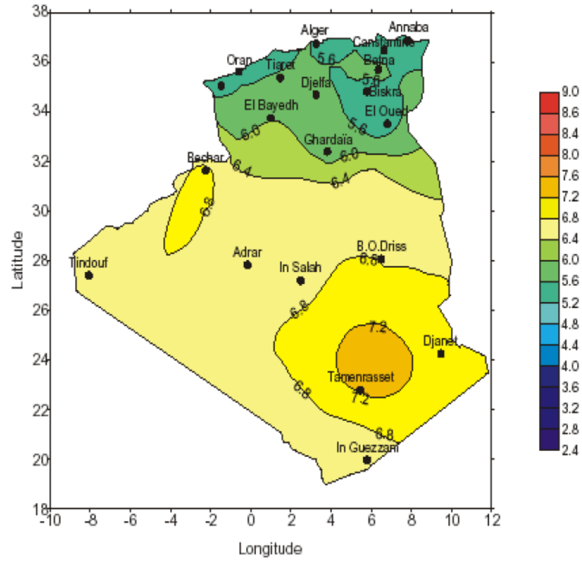


Fig. 2 Solar radiation in Algeria

The sunshine duration on the whole national territory exceeds the 3000 hours annually and even reaches 3900 hours on the high plateaus and the Sahara [11].

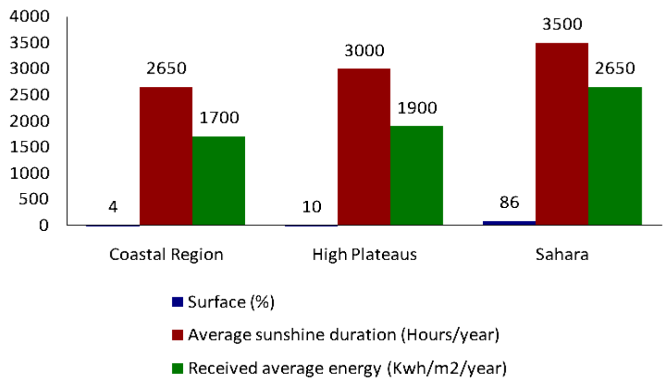


Fig. 3 Solar potential in Algeria

Photovoltaic solar energy refers to the energy recovered from sunlight and transformed directly into electricity through photovoltaic panels. It results from direct photon-to-electron conversion in a semiconductor. In addition to the advantages related to the fact that photovoltaic systems do need low cost maintenance, this energy fully meets the needs of facilities in remote areas where connection to the grid is too expensive.

Photovoltaic solar energy is a non-polluting source of energy. The modularity of the photovoltaic solar system allows for innovative and aesthetic use of its components in architecture.

The energy strategy of Algeria is based on the acceleration of the development of solar energy. There are several ongoing electrification projects in rural areas using solar energy as a supplement to classical power grid. Photovoltaic systems are also successfully used for water pumping for the development of steppe areas. Another program for Saharan areas electrification using photovoltaic systems is carried out for the benefit of remote southern populations. These programs of solar energy supply give to the population of far villages a first access to information and communication since provided electricity makes possible to ensure various services.

IV. Calculation of Solar Flux

Points of measurement of solar radiation may remain relatively numerous. Comprehensive weather data that are needed are indeed most often lacking. Therefore, try to deduce the solar radiation parameters known or easily estimable using empirical formulas derived from the statistical analysis of previous measurements made on the spot or in comparable environments or weather data from more basic. To determine the direct and diffuse solar flux we base on the method suggested by Chouard et al (1977) suggest that empirical formulas [12] and develops a bond graph model.

A. Direct flow

Direct radiation on the surface assumed to be horizontal cries as follows:

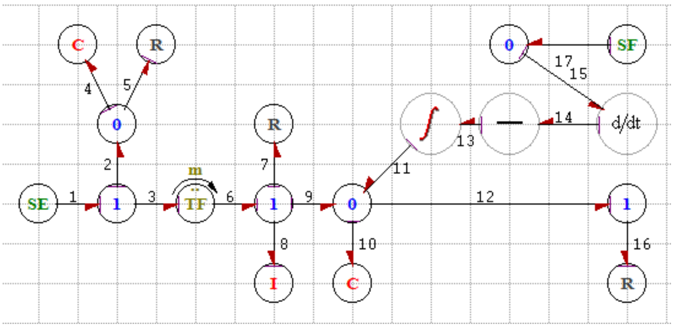


Fig. 4 Bond graph model for calculation of direct flow

Several mathematical formulations of atmospheric disturbance are proposed in the literature [13-20]. In this study the coefficient of disorder is represented by the element C, Se: solar constant = $1380 W/m^2$, R: coefficient of earth sun distance, TF: height of the sun on the horizon.

B. Diffuse flux

Correlations showed a clear diffuse flow was a function of the height of the sun TF. According to [21], Chouard et al (1977) assume in first approximation that the diffuse flux is proportional to sin (h), and based on statistical studies conducted in the U.S. found from experimental propose the following equation to calculate the diffuse flux:

$$R_d = I_0\lambda_i\left[0.271-0.2939A_1\exp\left(\frac{-A_2}{\sin(h)}\right)\right]\sin(h) \qquad (1)$$

Corresponding bond graph model is shown in the following figure (Fig. 5)

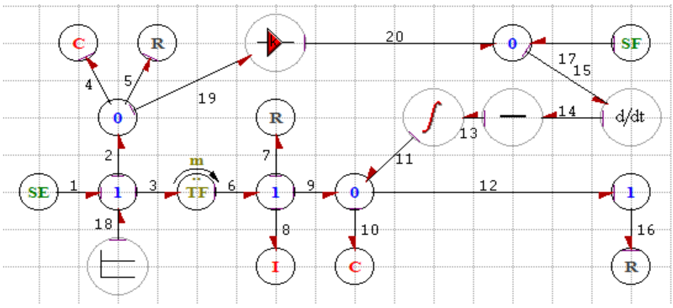


Fig. 5 Bond graph model for calculating diffuse flux

C. Global radiation

Global radiation consists of direct radiation and diffuse radiation [14]. His bond graph model is given in figure 6.

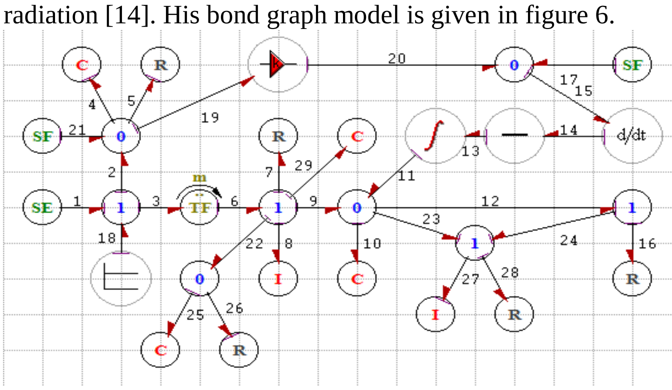


Fig. 6 Bond graph model to calculate the global radiation

The bond graph model is relatively accurate and has the advantage of ease of use. Coefficients C depend disorder clarity of the sky seen time and place and were numerically identified from meteorological data. The values that we used in this study are from [1].

V. Validation of Models

We applied the methodology to calculate the bond graph hourly solar radiation on radiometric station Bouzaréah (CDER) as follows: Having monthly averages of sunshine, we generate data under clear-sky irradiation time and average sky for different plans. We compared the values of solar radiation provided by two stations with the values calculated by the models.

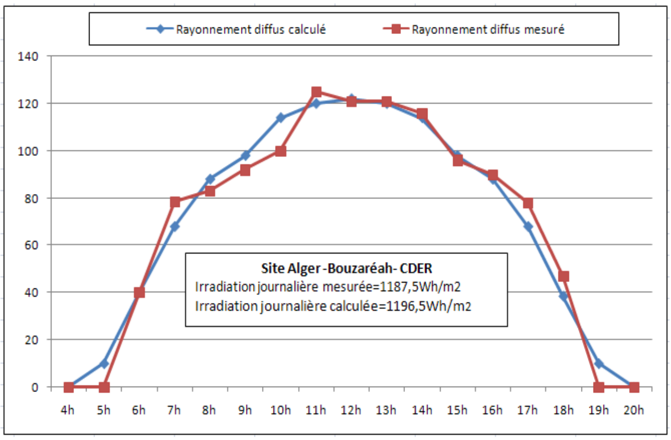


Fig. 7 Daily diffuse radiation on horizontal surface

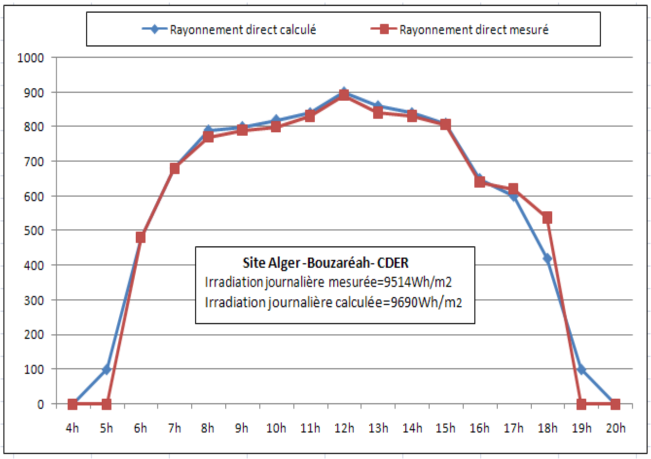


Fig. 8 Daily direct radiation at normal incidence

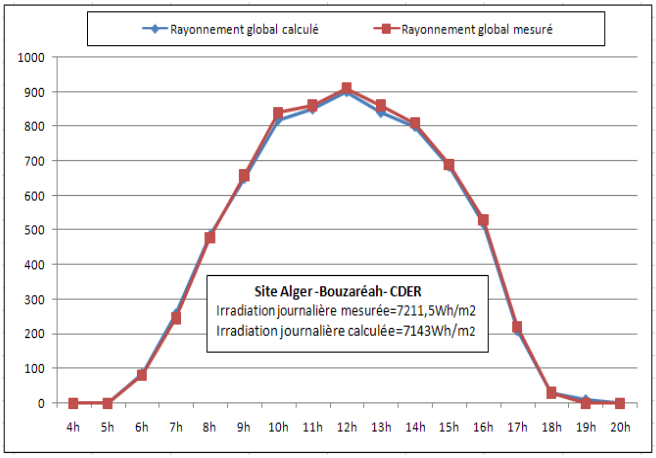


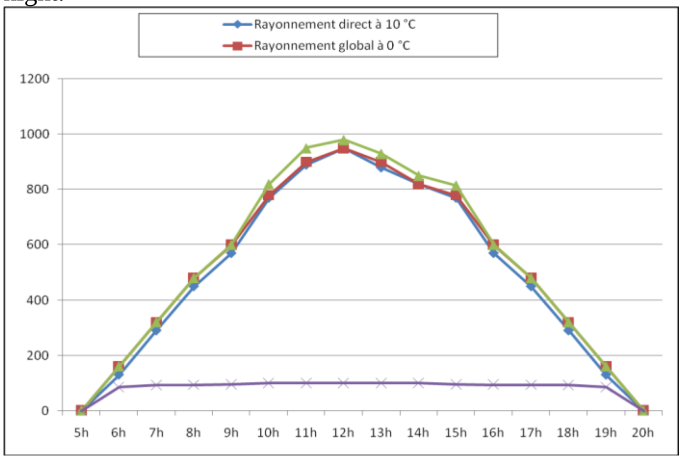
Fig. 9 Daily global radiation on inclined surface at 36.8 °

VI. APPLICATION OF THE HIGHLANDS REGION

A. Characteristics of the region

To study the climate of a region, more data are needed as humidity, sun, snow and others. Knowledge of these factors is required because it affects human activities and consumption of energy production and habits in particular. Setif is located to the north east of Algeria, more accurately, 530 (longitude) and 3592 North (latitude). The altitude of the city changes from 512 m to 1130 m, the average altitude is about 821 m, it is distant about 110 miles from the sea It is located in an area characterized by cold winters with average temperatures around 8 ° C and relative humidity 63% and trying a hot summer with average temperatures around 38 ° C and can reach 45 ° C and above, with a relative humidity around 38%. It is confirmed that the model Capderou [1], used for the Atlas of Algeria, may well provide the distribution of radiation direct, diffuse and global radiation during the day representative months, particularly in July with small recorded errors.

Figure 10 shows the changes in direct and diffuse radiation for a day representative of July for the Setif region. It is clear that the region may have significant amounts of energy that can be exploited, especially between 10 am and 15 hours of night.



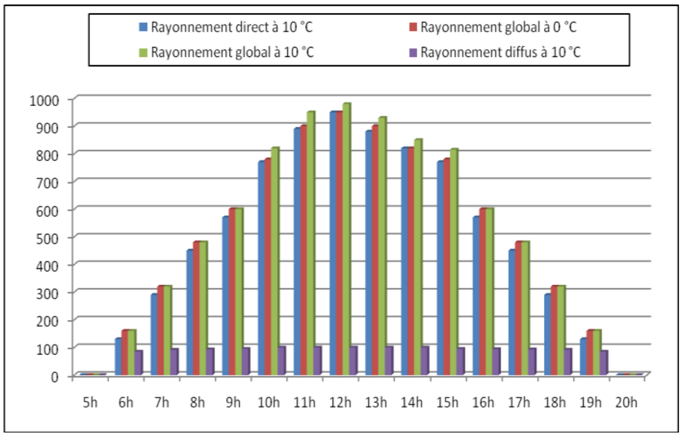


Fig. 10 Variation of radiation flux of direct and diffuse representative during the day of July in the region of Setif

Figure 11 shows an example of the global radiation curves for the town of Setif calculated from the bond graph model previously established.

This method of calculating the radiation allowed us to calculate the radiation in regions where weather data are not available.

Radiation thus calculated will be used to estimate the production of electricity in the northern, central and southern Sétif (Figure 11).

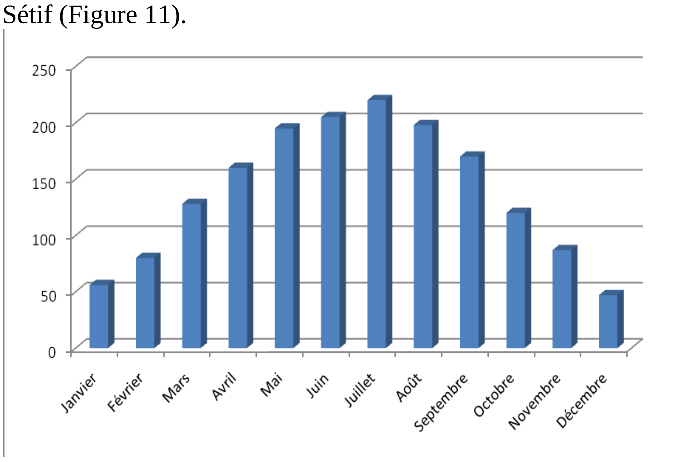


Fig. 11 Global solar radiation for the year calculated at the site of Setif

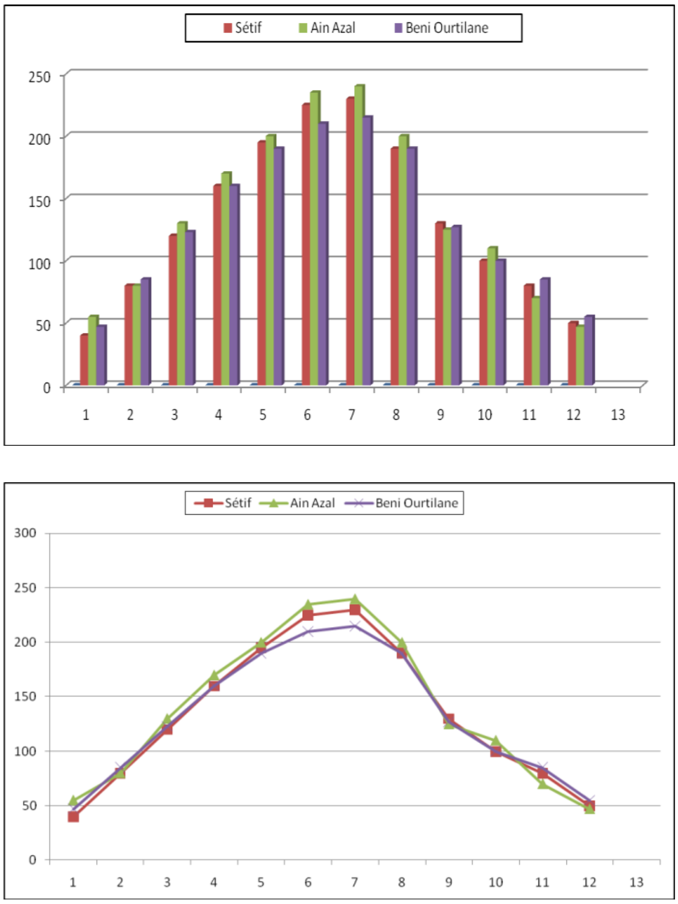


Fig. 12 Global solar radiation calculated for regions: Beni Ourtilane, Sétif and Ain Azal.

VII. Conclusion

The work in this paper aims firstly, to identify patterns bond graphs to calculate the various radiation fluxes involved in the energy balance, and secondly, to compare the results obtained from these models with measurements annual global solar radiation on a horizontal surface at the site of Bouzaréah (CDER) where data are available.

The comparative study between the measured and calculated values showed that a good agreement between the measured values and those calculated by the different bond graph models that can be used also for sites where the climate is similar to that of Sétif.

We also calculated the annual global radiation for three regions of different climates: The site of Sétif, the site of Ain Azal (south of Sétif) and Beni Ourtilane site (north of Sétif), and we note that the curves have the same gaits.

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