Computer Interface for The Determination of Optimum Tilt Angles For Photovoltaic Solar Panels

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ABSTRACT

The focus of this paper is on demonstrating a way to determine the optimum inclination angle at which solar panels should be tilted in order to harvest maximum radiation from the sun in any region of Nigeria. The computer program for this work written in Visual Basic 2008 runs in a user friendly way and comprises an interface for the determination of the yearly fixed optimum tilt angle of solar panels based on the principle of maximizing solar radiation using the Hay-Davis-Klucher-Reindl (HDKR) model and the equations of Duffie and Becmann as well as estimates from the Photovoltaic Geographic Information System. The user is prompted to select geographical region, state and city location after which the computer program automatically search and store the latitude and longitude of the user's location. Once all data has been correctly entered, the user clicks on the display button to display the result of the optimal angle at which a solar panel to be installed in his or her location should be titled. The computer interface was tested using yearly radiation data for Ilorin in kwara state. The result was validated by comparison with that of the Photovoltaic Geographic Information System (PVGIS) and the work done by M.S Okundamiya and A.N Nzeako. From the output of the computer interface, this conclusion was reached: (i) the yearly angle of tilt of a solar panel installed in any region in Nigeria is approximately equal to the latitude of the region.

Keywords: Computer interface, determination of optimal inclination angle, solar photovoltaic system

iSTEAMS Proceedings Reference Format
Kadiri, S.O. & Akinwande, F.A. (2019): Computer Interface for The Determination of Optimum Tilt Angles For Photovoltaic Solar Panels. Proceedings of the 17th iSTEAMS Multidisciplinary Research Nexus Conference, D.S. Adegbenro ICT Polytechnic, Itori-Ewekoro, Ogun State, Nigeria, 21st – 23rd July, 2019.Pp 69-76 . www.isteams.net - DOI Affix - https://doi.org/ 10.22624/AIMS/iSTEAMS-2019/V17N2P8

1. INTRODUCTION

One of the problems usually encountered by solar panel installer includes but not limited to knowing the right angle of inclination of a fixed solar panel with respect to the horizontal and the right orientation where the solar panel should face with respect to the sun. Installing solar panels at the right angle of inclination and orientation to the sun will make it possible for the solar panel to harvest the optimum amount of solar radiation. The computer program for this work written in Visual Basic 2008 provides a way of accurately predicting the maximum angle of tilt or inclination angle of a solar panel with respect to the horizontal to generate maximum output from the solar panel.

1.1 System configurations

Solar power system is one of the renewable energy systems which use PV modules to convert sunlight into electricity [1]. There are basically three photovoltaic system configurations: stand alone, grids connect and hybrid system. **(1) Stand-alone** PV system: It operates independently on any other power supply and it usually supply electricity to a dedicated load(s). It may include storage like battery bank to allow electricity to be provided during the night or at times of poor sunlight level. (**ii) Grid connected System:** It operates in parallel with the conventional electricity distribution system. It can be used to feed electricity into the grid distribution system or to loads which can also be fed from the grid. **(iii) Hybrid System:** it makes it possible to add one or more alternative power supplies (e.g. diesel generator, wind turbine) to the system to meet some of the load requirements. This kind of power combination is known as hybrid systems. It can be used in both stands alone and grid connected application.

1.2 Major system components:

Major components for solar PV system are photovoltaic array (which include wiring and mounting structure), solar charge controller, inverter, battery bank, auxiliary energy sources and loads (appliances). The various system components are discussed below.

(i) Photovoltaic cell: Cell is the basic photovoltaic device that is the building block for PV modules. One silicon solar cell produces 0.5 volt. 36 cells connected together have enough voltage to charge 12 volts batteries and run pumps and motors

(ii) Photovoltaic module: A group of Photovoltaic cells connected in series and/or parallel and encapsulated in an environmentally protective laminate to converts sunlight into electricity. 72 cell modules are the standard for grid connected systems having a nominal voltage of 24 volts and operating at about 30 volts.

(iii) Panel: A structure group of modules that is the basic building block of a PV array. The three basic types of solar panel are mono crystalline, poly crystalline and amorphous solar panel. The three basic types of solar panel are discussed below:

Mono crystalline solar panel: This solar cell uses very pure silicon and involves a crystal growth process. Long silicon rods are produced which are cut into slides of 0.2 to 0.4mm thick discs or wafers which are then wired together in the solar panel. The most efficient and expensive solar panel are made with mono crystalline solar cells.

Poly crystalline solar panel: Often called multi crystalline solar panels made with polycrystalline cells are a little less expensive and slightly less efficient than mono crystalline cell because the cells are not grown in single crystals block of many crystals. This is what gives them that sticking shattered glass appearance like mono crystalline cells; they are also then sliced into wafers to produce the individual cells that make up the solar panel.

Amorphous solar panels: These are not really crystals but a thin layer of silicon deposited on a base material or glass to create the solar panels. These amorphous solar panels are much cheaper, but their efficiencies also much less, so squarer frottage is required to produce the same amount of power as the mono crystalline or poly crystalline type of solar panel. Amorphous solar panel can even be made into long sheets of roofing materials to cover large areas of south facing roof surface.

(iv) Array: A group of panels that comprise the complete direct current PV generating unit and by convention the array components are split into the photovoltaic parts (the PV modules themselves) and the balance of system components.

(v) The Balance of System: This is the balance of the equipment necessary to integrate the PV array with the site load. This includes the array circuit wiring, fusing, disconnects, and power processing equipment (inverter)

(vi) Load: Are electrical appliances that are connected to solar PV system such as lights, radio, TV, computer, refrigerator etc. it is necessary to determine if the load will be d.c or a.c for effective system design

(vii) Solar panel mounting structures: The main purpose of the structure is to hold the module in the required position without undue stress. The structure may also provide a route for the electrical wiring and may be free standing or part of another structure (e.g. a building). It must be capable of withstanding appropriate environmental stresses such as wind loading for location and it must allow for easy dissipation of heat [1]. The three types of solar panel array mountings include fixed, adjustable and tracking solar panel mounting.

Fixed solar panel array mounting: Is a type of solar panel mounting system that is comparatively stationary. The solar panel should always face the equator (due south in the northern hemisphere and vice versa)

Adjustable solar panel: The angle of inclination of an adjustable solar panel mount can be changed two or more times during the year to account for the lower angle of the sun in winter as the earth orbits the sun causing seasonal change.

Tracking solar panel mounts: It is a type of solar panel mount that follows the path of the sun during the day to maximize the solar radiation that the solar panel receives. A single axis tracker tracks the sun and seasonal declination movement of the sun. This is the most efficient mounting type but costly

Electrical connection of cells and modules: In order to provide the appropriate quality of electrical power, a number of cells must be electrically connected. There are two basic connection methods: series connections in which the top of contact of each cell is connected to the back contact of the next cell in sequence, and parallel connection in which all the top contacts are connected together the same as the bottom contacts. As with connection of cells to form modules a number of modules can be connected in series to increase the voltage level and in parallel to increase the current level or in combination of the two. The exact configuration depends on the current and voltage requirement of load circuitry fed by the system output.

2. MODELS FOR ESTIMATING GLOBAL RADIATION FALLING ON A TILTED SURFACE

The global radiation striking the surface of the earth is composed of three components. These include the beam radiation, diffuse radiation and the reflected radiation on the earth surface. The reflected radiation on the earth is usually approximated by the term albedo. The beam radiation is the solar radiation that travels from the sun to the earth's surface without any scattering by the atmosphere [9] while diffuse radiation is the solar radiation whose direction has been changed by the earth's atmosphere. Diffuse radiation comes from all parts of the sky and does not cast a shadow. To calculate the global radiation striking a tilted surface, Homer [9] uses the HDKR model, which assumes that there are three components to the diffuse solar radiation: an isotropic component which comes from all parts of the sky equally, a circumsolar component which emanates from the direction of the sun, and a horizon brightening component which emanates from the horizon. The equation given by [9] for calculating global radiation is as given below:

$$G_\beta = (G_b + G_d A_i) R_b + G_d(1 - A_i)\left[\frac{1+\cos\beta}{2}\right]\left[1 + f\sin^3\left(\frac{\beta}{2}\right)\right] + GP_g\left[\frac{1-\cos\beta}{2}\right] \quad (1)$$

Where,

G_β is the global radiation collectible on an inclined solar panel, G_b is the beam radiation component of the global radiation, G_d is diffused component of the global radiation, β is inclination angle and P_g is albedo. Anisotropy index, with symbol A_i, is a measure of the atmospheric transmittance of beam radiation. This factor is used to estimate the amount of circumsolar diffuse radiation, also called forward scattered radiation. The anisotropy index, A_i can be expressed by the following equation:

$$A_i = \frac{G_b}{G_o} \quad (2)$$

The cloudiness index factor (f) is a factor used to account for 'horizon brightening', or the fact that more diffuse radiation comes from the horizon than from the rest of the sky and is given by the following equation:

$$f = \sqrt{\frac{G_b}{G_o}} \quad (3)$$

R_b is the ratio of beam radiation on the tilted surface to beam radiation on the horizontal surface. The equation for R_b is as given by $R_b = \frac{\cos\theta}{\cos\theta z}$ (4)

θ is the angle of incidence for a surface with any orientation. The angle of incidence is the angle between the sun's beam radiation and the normal to the surface. The angle of incidence can be defined by the following equation:

$$\cos\theta = \sin\delta\sin\emptyset\cos\beta - \sin\delta\cos\emptyset\sin\beta\cos\gamma + \cos\delta\cos\emptyset\cos\beta\cos\omega \quad (5)$$

$+ \cos\delta\sin\emptyset\sin\beta\cos\gamma\cos\omega \quad + \cos\delta\sin\beta\sin\gamma\sin\omega$ .While the azimuth angle is the angular orientation of the solar collector towards the north, east, west or south of the equator. It is 0° at the north of the equator, 90° at the east of the equator, 180° south of the equator and -90 ° west of the equator. According to [6], for optimum solar efficiency, the solar panel should always face the equator due south in the northern hemisphere and due north in southern hemisphere. Since Nigeria is in the northern hemisphere, the solar panel should be south facing. Therefore, azimuth (γ) is equal to 180° or 0°.If γ =0, then equation (10) reduces to:

$\cos\theta = \sin\delta\sin\emptyset\cos\beta - \sin\delta\cos\emptyset\sin\beta + \cos\delta\cos\emptyset\cos\beta\cos\omega + \cos\delta\sin\emptyset\sin\beta\cos\omega$ (6)

The zenith angle, θz is define as the angle between a vertical line and the line to the sun. The zenith angle is zero when the sun is directly overhead and 90° when the sun is at the horizon. Because a horizontal surface has a slope of zero, we can find an equation for the zenith angle by setting $\beta = 0°$ in (6) above.

This yield: $\mathrm{Cos}\theta z = \cos\emptyset\cos\delta\cos\omega + \mathrm{Sin}\emptyset\mathrm{Sin}\delta$ (7)

3. THE IRRADIATION COLLECTIBLE AT OPTIMAL INCLINATION ANGLE

The irradiation collectible at optimal inclination angle, $G\beta opt$ is calculated by substituting β in (1) with βopt-optimal inclination angle as shown below:

$G\beta opt = (G_b+G_dA_i)R_b+G_d(1-A_i)[\frac{1+\cos\beta opt}{2}][1+f\sin^3(\frac{\beta opt}{2})] + GP_g[\frac{1-\cos\beta opt}{2}]$ (8)

The optimal inclination angle is that inclination angle from the horizontal at which the angle between the sun rays and the solar panel will be 90. The mathematical principle of differentiation which is useful for determining maximum and minimum point of an equation is also useful for determining optimum inclination angle. Differentiating $G\beta opt$ with respect to βopt in equation (8) above gives;

$\beta_{opt} = \tan^{-1}((\mathrm{Cos}\omega\mathrm{Tanlat} - \mathrm{Tan}\delta) / (\mathrm{Cos}\omega + \mathrm{TanlatTan}\delta))$ (9)

Figure 1 on the next page is the flow chart for processing user's inputs

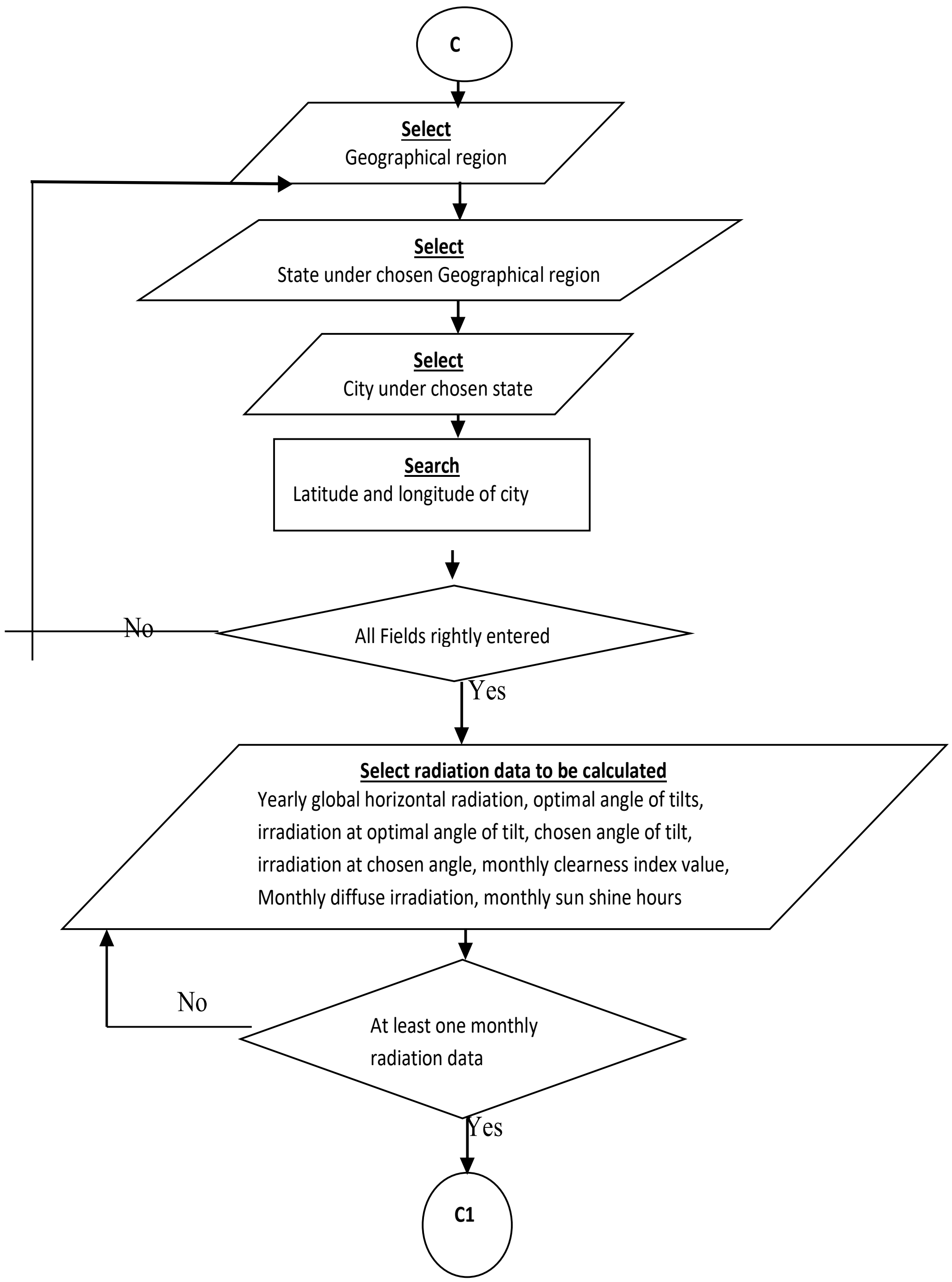

Figure 1: Yearly fixed radiation program flow chart written to process user's inputs

4. RESULTS AND CONCLUSSION

A sample input page and program output result for Ilorin, north central, Nigeria yearly radiation data is as shown in Figure 11 and figure 12 below. The program output consists of global horizontal irradiation data, optimal inclination angle, radiation at optimal inclination angle, irradiation at chosen angle, clearness index, cloudiness index, diffuse irradiation and sunshine hours. Also Table 1 below (gotten from the interface for yearly radiation output), depicts the yearly average optimal inclination angle (°), yearly average irradiation (kWh) and locations latitude and longitude. It can be seen from table 5 above that the yearly average optimal tilt angle (°) for the states representing each geographical region is approximately equal to the latitudes of such locations.

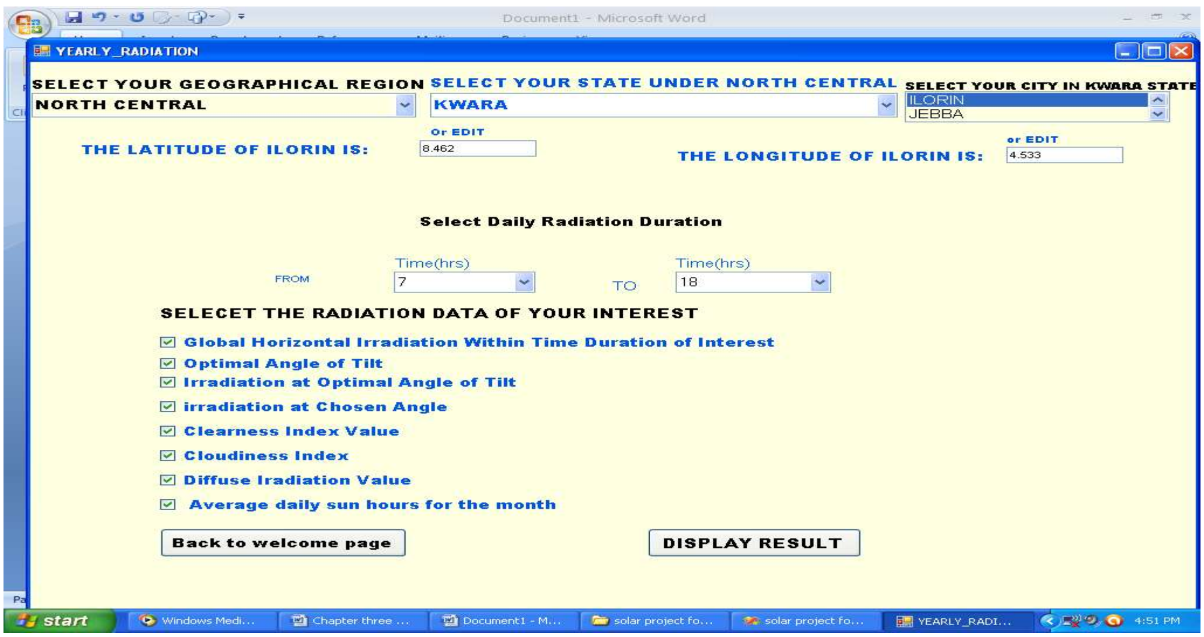

Figure 2: Interface of yearly radiation input page for Ilorin, Kwara state

Table 1: Yearly Average Optimal Inclination Angle (deg) and Yearly Average irradiation (kWh) for the six geographical regions in Nigeria

Region/State	Location latitude (°)	Yearly average optimal inclination angle	Yearly average irradiation (kWh)
North central(Kwara)	8.462	8.06934	5.64787
North east (Bornu)	11.166	11.17572	6.323149
North west (Sokoto)	13.183	13.2071	5.675282
South east (Enugu)	6.85	6.872515	4.393546
South west (Ogun)	6.466	6.48191	4.833943
South south (Edo)	7.066	6.053889976	3.921542

5. CONCLUSION

Energy is needed in all sectors of the economy and much of the energy consumption in Nigeria comes directly from petroleum which is now in short supply and unfriendly to the environment. Solar energy as a renewable source of energy if well utilized can cater for energy needs of Nigeria as a country. It was determined that for maximal solar energy collection, a solar panel must be installed to collect solar energy at the right angle of inclination and at the right orientation.. The program for this project work written in Visual Basic 2008 has successfully addressed this problem of determining the yearly fixed optimum tilt angles for photovoltaic solar panels that is south facing in any states of Nigeria. The information provided by this work will be very useful for energy planners, forecasters, engineers and solar panel installer alike. Also this work will serve as an encouragement to reduce over dependence on petroleum as the major source of energy and to focus attention on renewable source of energy like solar energy.

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