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Stand-alone Solar Photo-voltaic Systems for Off-grid Electrification

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Abstract
Electric energy is necessary to meet the daily needs of the population, as it is used in cooking, heating, irrigation, lighting, and others. There are many residential areas far from the public electricity network, hence the importance of solar energy in meeting the needs of these residents. This paper will study the design of a solar photo-voltaic system with a capacity of 131.6 kwh. The needs and requirements will be studied first, then a design will be made for the parts of this system such as inverters, batteries, and photo-voltaic panels. The results that we will obtain will confirm that this energy system is able to meet the necessary needs with high efficiency, and will also confirm that it is environmentally friendly in terms of carbon emissions. We will take Tanzania as a case study; the designed system contains 108 panels and about 8 kw battery bank to supply the load.

Keywords: *Carbon emissions, PV, Grid-off, Solar energy, Stand-alone.*

1. Introduction

Most of the investments in the energy sector turned towards fossil fuels because of its low price, and this made reliance on renewable energy such as sun and wind moving at a slow pace [1]. The lack of oil and gas resources, high production costs, and increased demand for energy, along with climate change in recent years, are factors that have accelerated the shift towards dependence on renewable energies [2]. Renewable energies offer the benefit of being limitless, and can be utilized in a distributed fashion in the regions where they are implemented. Additionally, there is support for small and micro-grids [1, 2].

The renewable energy sector is witnessing rapid growth, due to several factors: the increase in energy demand due to the increase in population, the need to diversify energy sources due to the lack of oil and gas resources, the need to reduce carbon emissions and confront global warming, in addition to saving the cost of production [3]. In 2017, the energy generated from renewable energy was about 5350 MWh (53.6%), for bioenergy 3297.1 MWh (33%) for hydro energy, 287.3 MWh (2.9%) for wind energy, 397.7 MWh (4.0%) for solar energy PV, 396.6 MWh (4.0%) solar thermal, and 252.4 MWh (2.5%) geothermal energy [4]. The world population is currently estimated at about 8 billion, and growth projections indicate that by 2030 it will reach 9 billion. About 70% of the population lives in rural areas with the vast majority located in developing countries [5]. Most of the rural population is unable to access energy sources that rely on fossil fuels due to transportation difficulties and the limited reach of public electrical networks. As a result, they rely on traditional energy sources such as firewood and animal dung for heating, cooking, lighting, and other needs. However, this type of energy has significant environmental and health impacts. Trees are often cut down from forests and lands, leading to deforestation and ecosystem destruction. Additionally, smoke inhalation from these traditional energy sources can cause significant harm to respiratory health [6]. The operation of the island is the exceptional, stable operation of a part of the electrical network after its separation from the other system as a result of an error occurring somewhere, which may lead to the operation of a number of sources (units and power stations). Perhaps the separated part (by measuring the active power and (or) reactive power of the sources) overflow or scarcity. Island operation is combined with a large fluctuation in frequency and voltage. For the island operation control method, the range in the island frequency must be maintained between 49.8 Hz to 50.2 Hz. In the case of a fixed frequency system, it means that the power generated (Pg) is almost equal to the power consumed by the load (Pl), in addition, the frequency will decrease when the power generated is less than the power required by the load. Moreover, in the case of more power generated than (excess) power required by the load, the frequency of the system will increase. Energy flow is usually thought of as the solution to a set of energy balance equations. It was possible to determine the parameters of the power system from circuit theory. The distribution system is a circuit with one compound voltage source (three-phase) that may contain elements of constant resistance, and possibly some elements of constant current, and some elements with a non-linear relationship between voltage and current (constant power elements) [7]. To solve the non-linear system, we replace the nonlinear elements with equivalent linear elements. We then use the nodal or loop solution to solve the new system. Recalculating the linear equations in the solution results in a fundamental iterative method for solving the energy flow problem [8]. One way to solve the equivalent linear circuits is to reduce the network iteratively in order to find a driving point for the linear equivalent of each vector. These equations are used to calculate the values of voltages and currents in the network [9]. A unique approach utilizing the grey wolf optimizer (GWO) algorithm has been created to calculate the photovoltaic solar cell model [10]. A new approach called the multi-group salp swarm algorithm (MGSSA) has been developed to estimate photovoltaic (PV) solar cell models. This algorithm is based on the social behavior of salps and is known as a metaheuristic technique called SSA [11]. Renewable energy has become a popular subject of study at both the graduate and undergraduate levels, as well as gaining increased attention from society as a whole. Its usage is rapidly expanding in many parts of the world due to its numerous benefits, including the ability to provide energy such as electricity and heat with minimal environmental impact [12]. The novelty of this paper is Proving that the effectiveness of the solar energy system is no less important than fossil energy sources, and that research in this field will be a step for humanity to preserve the planet and the continuation of life on it.

2. Problem statement

2.1. Renewable energy in Tanzania

In Tanzania, the power system is operated by a state-owned company, in addition to independent power producers. Most of them have the license to sell energy directly to customers. Islands always occur when the main network is down due to a line outage. The license is offered to independent power producers who generate electricity from renewable energy sources such as solar, wind, etc.
There are many environmental and economic benefits of connecting the isolated network to the main network. When the working network is connected to the electrical network, the technical problems become less than if it was isolated from it. In the isolated situation, we maintain the stability of the system by solving technical problems within a section isolated from the distribution network Through:

a) Maintain frequency and voltage within acceptable levels.
b) Provide a ground reference/neutral grounding for the duration of the reflux.
c) Achieving acceptable liquidation of faults.
d) Synchronize the voltages and frequencies of the island and main mill before re-sealing the island section of the grid to the main grid.
e) Maintaining power balances between the load and the power generated by the island and the grid.

Tanzania is considered one of the countries that have large quantities of renewable energy sources, most of these sources have not been exploited to a large extent, hydroelectric energy has been developed to generate electricity, but solar energy is still below the required level despite the presence of sufficient solar saturation for [16].

2.2. Solar photovoltaic in Tanzania

The electricity generated from the photovoltaic panels is considered one of the sources of clean and environmentally friendly renewable energy. The energy collected from the panels is transformed into several forms such as heat and electricity, using different technologies. However, the economic feasibility of this energy depends on the location [17]. The sun's rays hit the earth at angles ranging from 00 (just above the horizon) to 900 (just above the horizon), because the earth is round and revolves around the sun and its orbit. The earth has great lines drawn from the west and east which are the equator (00), Tropic of cancer (23.50), north of the equator and the tropic of capricorn (23.50), south of the equator. On June 21, the sun will be above the tropic of cancer, when it will be summer in the northern hemisphere and winter in the southern hemisphere. Also on december 21st, the sun is above the tropic of capricorn which is winter in the northern hemisphere and summer in the southern hemisphere. The region experiences a tropical climate bordered by the tropics which are the tropic of cancer in the north and the tropic of capricorn in the south. In the tropics there are two seasons in a year in which there is a rainy season and a dry season. However, the area north of the tropic of cancer, south of the tropic of capricorn, experiences four seasons in a year: winter, fall, spring, and summer. When the sun's rays are vertical, the earth's surface will have maximum energy. When the sun's tilt increases, so will its distance. It passes through the atmosphere, and thus becomes more dispersed and diffuse [15].

The geographical location of Tanzania is a major support factor for solar energy generation throughout the year. It is estimated that the intensity of solar radiation reaches 4-7kWh/m^2/day with hours of brightness ranging from 2800-35000 MW of photovoltaic power has been installed in various sectors such as schools, homes, hospitals and streets by the state and with the participation of the private sector [14, 15]. Most off-grid systems include photovoltaic panels, inverters and batteries.

2.3. Solar PV categorization

Available solar PV systems in Tanzania range from small pico applications such as small cell phone chargers to solar home systems (SHS) [15]. Solar PV is considered to be a distinct type of technology, however it is quite different in terms of technical characteristics, capital and scale [16].

When installing and operating photovoltaic systems, the maximum power point tracking (MPPT) of the solar array must be reached. In addition to the role of this technology in increasing the energy supplied from the solar PV system to the load, it is considered as a lifetime booster [17].

2.4. Stand-alone solar PV system

The independent solar energy system consists of a row of photovoltaic panels, in addition to a charging regulator for the batteries that protects them from overcharging and undercharging, there are also batteries that are an energy storage, and there is an inverter whose task is to convert direct current into alternating current [18]. Standalone systems are used more widely than grid-connected systems due to their ease of installation and lack of breakdowns. The principle of operation of these systems is simple, as the energy from the sun is collected through the panels to convert it into direct current. The energy passes through the charging regulator and inverter to feed the alternating current loads. The panels are stored in batteries to be used at night or when the sun is out.

3. Basic calculation relationships and assumptions

3.1. Solar cell

There are two main types of photo-voltaic solar cells: crystalline cells and thin films. Crystalline cells make up about 90% of grid-connected photo-voltaic systems worldwide [20]. While crystalline cells are more expensive, they are more efficient and have a longer operating life. Silicon cells are produced by having a top layer of boron and a bottom layer of phosphorus. These layers create a "depletion zone" between them and the resulting electric field [21]. Using photo-voltaic modeling, electricity generation is directly converted from the sun's energy by photovoltaic cells. The photovoltaic system is modeled by connecting a current source in a parallel and inverting diode connected together with a series and parallel resistance [22].

3.1.1 Single diode model

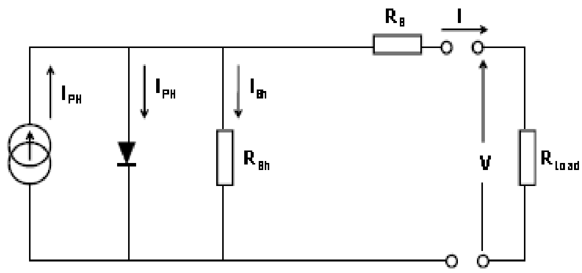

Figure 1. Solar cell modeling using one diode.

Expression of single diode as Irs is module reverse saturation current, T is operating temperature, Isc is short circuit current, Iph is photo current, Ir is solar irradiation, and ki is short circuit of cell at some particular temperature and radiation.

$$\mathbf{I_{ph}} = (\mathbf{I_{sc}} + \mathbf{k_i}(\mathbf{T} - \mathbf{298}))\frac{\mathbf{I_r}}{\mathbf{1000}} \quad (1)$$

$$\mathbf{I_{rs}} = \frac{\mathbf{I_{sc}}}{\mathbf{exp}\left(\frac{\mathbf{qV_{oc}}}{\mathbf{N_s KnT}}\right) - \mathbf{1}} \quad (2)$$

where q is electron charge (1.6×10^{-19} C), Voc is the solar module open circuit voltage (21.24 V), Ns is the number of cells connected in series, k is the Boltzmann constant (1.3805×10^{-23} J/K), n is the ideality factor (1.6).

The temperature varies according to change in altitude and the period of the year that is rain season or dry season.
The module saturation current I0 varies with the cell temperature, which is given by:

$$I_0 = I_{rs}\left(\frac{T}{T_n}\right)^3 \exp^{\frac{q\times E_{go}}{nk}}\left(\frac{1}{T}-\frac{1}{T_n}\right) \quad (3)$$

Here, Tn: nominal temperature is 298.15 K, Eg0: band gap energy of the semiconductor is 1.1 eV.
The current output of PV module is:

$$I = N_p I_{ph} - N_p I_o\left(\exp^{\frac{\frac{V}{N_s}+I\frac{R_s}{N_p}}{NV_t}} - 1\right) - I_{sh} \quad (4)$$

where Np is number of PV module connected in parallel, Rs is series resistance, Rsh is shunt resistance, and Vt is diode thermal voltage.

$$V_t = \frac{kT}{q} \quad (5)$$

$$I_{sh} = \frac{\left(V\frac{N_p}{N_s}\right) + IR_s}{R_{sh}} \quad (6)$$

3.1.2. The two diode models

The ideality factor n in the single diode equation is a function of the voltage across the device. Recombination is dominated by the surfaces and bulk regions at higher voltages; therefore, the ideality factor is close to unity. However recombination in the actual junction dominates at lower voltages, so the ideality factor increases to two.

3.2. System parameters

3.2.1 Input parameters

Table 1. Input parameters.

parameter	value
E_i	131.6 kwh
PV module	320 w
Peak-sun hour	6 h
Drop voltage	2%

3.2.2. Sun hours in Arusha

The average hours of sunlight in Arusha is ranging from 2,190 to 3,285 per year with an average of 7.3 hours of sunlight per day [23]. The average sunlight hours 8 hours per day in september to march and 6 hours for april to august per day in july and august, with an average radiation of 4.6 kWh/m² per day.
Insolation on an inclined plane was calculated by Lid and Jordan's equation:

$$K_T = \frac{H}{H_o} \quad (7)$$

$$H_o = \frac{24}{\pi} I_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) * \left(\cos\emptyset\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\varphi\sin\delta\right) \quad (8)$$

where Isc is solar constant (1367W/m^2), n is day number of year, $\emptyset$ is the latitude, δ is the solar declination, and ωs is sunset hour angle.

$$\omega_s = \cos^{-1}(-\tan\delta\tan\emptyset) \quad (9)$$

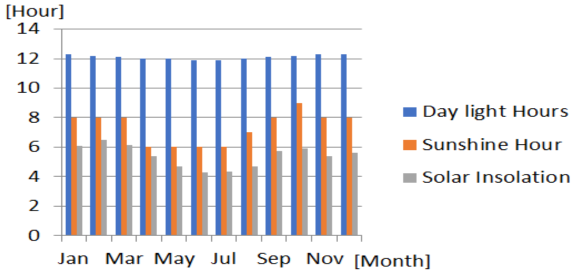

Figure 2. Day light, sunshine, and solar insolation in Arusha.

3.2.3. Energy demand calculation

When designing a solar energy system, the required amount of energy consumed per day must first be calculated [24]; the energy consumed for each device is calculated in W, with the number of hours required for operation, and the loads must be classified according to the timing of their operation [25]. The energy consumption for individual load is Wh and calculated by using the equation:

$$E_i = P_i * T_u \quad (10)$$

where Ei is energy demand per day of individual load in Wh, Pi is rating of individual load in watts, and Tu is time of use of that load in per day in hours.
Therefore, daily total energy required in Wh would be calculated by summing all individual energy for each appliance. Thus, daily total energy required for the system is represented in figure 2. From figure 2, total energy needed each day is 131545.7 Wh or 131.6 kWh.

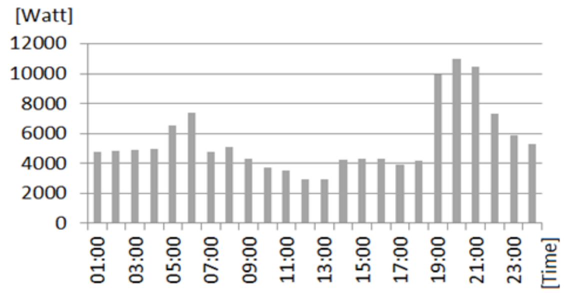

Figure 3. Daily Watt Hour required.

It has been observed that energy amounting to 30.26 kWh (23.0%) could be supplied directly from the energy harnessed from the solar panels while 101.3 kWh (77.0 %) need energy storage (used in the time of absence sun).

3.2.4. System loss attribution

The energy generated by the solar panels passes through several parts, which leads to the loss of part of it. The main causes of energy loss in the solar panels are shading, dust accumulation, an imperfect angle of inclination, and the cables that connect the solar panels to the various devices.

3.2.5 Sizing of PV array

The different rating of PV panels can generate different amount of power. Furthermore, all solar PV panels are always rated in peak-watts depending on the module size and the weather conditions of the selected site. Therefore, in calculating the size and number of PV modules needed for specific loads, the rated peak-watts of panel are required.

$$\mathbf{P_{t-pv}} = \frac{\mathbf{E_t}}{\mathbf{T_{peak-hours}}} \times \mathbf{1.57} \qquad (11)$$

where Pt-pv is the complete size of PV array in W, Tpeak-hours is the lowest daily average peak-sun hours of a month in a year and 1.57 represents the scaling factor.

The system take into consideration all system loses such as panel efficiency of 77%, storage batteries 85%, and wiring system 0.97%.

From figure 2 above it has been observed that the minimum sunshine hour in a year occurs in April, May, June, and July which is 6 hours of sun in a day. Therefore, total peak power required for the location would be computed as.

$$\mathbf{P_{t-pv}} = \frac{\mathbf{131.6\ kWh \times 1.57}}{\mathbf{6h}} = \mathbf{34.5\ kW} \qquad (12)$$

Hence, the number of PV modules or panels required the PV system is computed using the peak-watts obtained in equation (12):

$$\mathbf{N_{modules}} = \frac{\mathbf{P_{t-pv}}}{\mathbf{Wp_i}} \qquad (13)$$

where Nmodules is the total number of modules, Wpi is the rating in peak-watts of selected panel or module in watts.

$$\mathbf{N_{modules}} = \frac{\mathbf{34.5\ kW}}{\mathbf{0.32}} = \mathbf{108\ panels} \qquad (14)$$

3.2.6. Battery system

3.2.6.1. Rating of charge controller

The most important process related to batteries is to control the charge of the batteries and avoid overcharging and undercharging [26, 27]. To do this, the charging regulator must be chosen in proportion to the energy coming from the panels in addition to the size of the batteries [28]. Thus the ampere current rating of solar charge controller is calculated mathematically as:

$$\mathbf{I_{scc}} = \mathbf{I_{sc}} \times \mathbf{1.25} \qquad (15)$$

where I_{scc} is the size of solar charge controller in amperes, I_{sc} is the short circuit current rating of selected PV unit, and 1.3 represents the safety factor.

3.2.6.2. Sizing of battery bank

In the solar energy system, we need to have a battery bank in order to secure the electrical energy at night and on cloudy days, and the photo-voltaic panels must be sufficient to supply the load with energy in addition to charging the batteries during the hours of peak solar radiation. There are different types of rechargeable batteries, such as lithium, gel but the most popular are lead-acid batteries [29]. The battery capacity is in ampere hours (Ah). The following factors are taken into account when calculating the battery bank size:

a) The amount of energy required to be consumed when the sun is out
b) The number of cloudy days
c) the coefficient of discharge of the battery
d) The nominal voltage of the battery

Usually the estimated number of cloudy days is 3. Therefore, the battery capacity should be 1.5-3 times calculated rating to compensate energy during cloud and raining days [30]:

$$\mathbf{Ah_{bank}} = \frac{\mathbf{E_t}}{\mathbf{V_{dc-sys}}} \times \mathbf{D_{aut}} \times \mathbf{1.25} \qquad (16)$$

Therefore, by considering figure 2 above, the appliances supplied with energy between 10:00 to 15:00 (6 hours of lowest sunny day) are not considered for energy storage. These can be directly supplied by the solar panel hence reducing the cost of battery banks. Therefore, from figure 2, energy consumed by the appliances between 10:00- 15:00 is 21.66 kW which has to directly supply to the appliances while 109.9 kW need battery bank for energy storage. Therefore, total energy taken into consideration when calculating storage battery bank is 109.9 kW.

$$\mathbf{Ah_{bank}} = \frac{\mathbf{109.9 \times 3 \times 1.25 \times 1000\ kWh}}{\mathbf{48V}} \quad (17)$$
$$= \mathbf{8586\ Ah}$$

3.2.7. Sizing of cables

The various components of the independent photovoltaic system are connected through cables. The required cable size is designed according to the value of the maximum current that the cable will carry, taking into account also the voltage drop that occurs along the cable length to the permissible limit. The cable used in solar energy systems must be resistant Waterproof and sunlight. Therefore, system must be correctly sized in order to minimize voltage drops which are not exceeding 2%. The voltage drop in a current carrying conductor is calculated as:

$$\mathbf{V_d} = \frac{\boldsymbol{\rho} \mathbf{L I_{max}}}{\mathbf{A}} \quad (18)$$

where ρ is the resistivity of the conducting wire material in ohm-meters, L is the length of cable, V_d is the maximum permissible voltage drop in cable, and I_{max} is the maximum current carried by the cable.

4. Algorithm and result

In the algorithm, all non-linear circuit element models have been replaced by linear equivalent. The component model of a distribution system is a radial interconnection of the elements such as (substation) constant voltage sources, lines, constant impedance elements, switches, transformers, shunt capacitors, and loads [31].

There is the linearity of current and voltage in the circuit elements of the power system except for the complex power devices such as co-generators and constant PQ loads.

$$\mathbf{\bar{I}(V)} = \left(\frac{\mathbf{\bar{S}}}{\mathbf{V}}\right)^* \quad (19)$$

where $\bar{S}$ is the constant complex power. Equation (20) consists of constant current, constant impedance or a combination of the two in order to form linear expression.

$$\mathbf{\bar{I}(V)} = \mathbf{\bar{I}} + \mathbf{\bar{Y}V} \quad (20)$$

After modeling the system , the following step is to build up the driving point that will reduce the circuit to form an equivalent circuit at each bus. Therefore, the Norton equivalent will be used in constructing all buses having incoming branches that would be combined with the sub-network supplied through that branch. Since the networks are dealt with as multi-phase networks, the compound Norton equivalents model with admittance matrix is used in representing the constant impedance part and a vector of the current injections. The currents and admittances are summed when building the Norton equivalent at bus k. The bus will have one or more incoming and outgoing lines would be connected in parallel to the following circuit elements: load, shunt capacitor, co-generator, and Norton equivalent for outgoing branches. Using the notation from figure 4, the current I_k' is written as a function of the bus voltage V_k'.

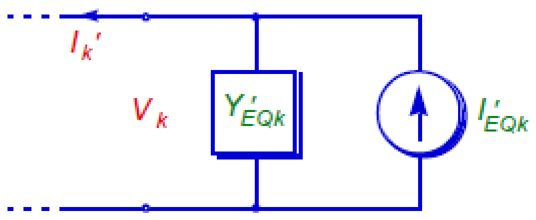

Figure 4. Norton equivalent at bus k.

$$\mathbf{I_k'} = \mathbf{I_{EQk}'} - \mathbf{Y_{EQk}'V} \quad (21)$$

The two parameters of the Norton equivalent are given by (22) and (23):

$$\mathbf{Y_{EQk}'} = \mathbf{\bar{Y}_{Lk}} + \mathbf{\bar{Y}_{Ck}} + \sum_{j} \mathbf{Y_{EQj}} \quad (22)$$

$$\mathbf{\bar{I}_{EQk}'} = \mathbf{I_{Lk}} + \mathbf{\bar{I}_{Ck}} + \sum_{j} \mathbf{I_{EQj}} \quad (23)$$

where $\bar{Y}_{Lk}$ is admittance of constant impedance load, $\bar{Y}_{Ck}$ is admittance of shunt capacitor, $\bar{I}_{Lk}$ is current injection to the power system network, $\bar{I}_{Gk}$ is current injection from the generator, $\bar{Y}_{EQj}, \bar{I}_{EQj}$ are Norton equivalent for incoming branch of bus j and j index of bus at receiving end of an outgoing branch of bus k.

The Norton equivalent at bus k is combined with the incoming branch as shown in figure 5. The parameters Y_{EQk} and I_{EQk} are computed from their primed values and the parameters of the branch.

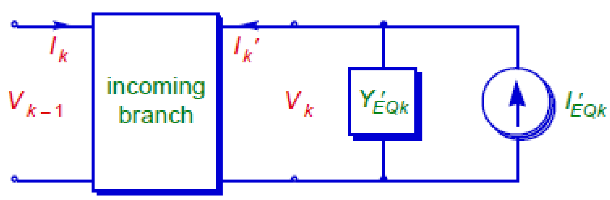

Figure 5. Combine with incoming branch.

$$\mathbf{I_k} = \left[\mathbf{Y_k^{11}} - \mathbf{Y_k^{12}}\left(\mathbf{Y_k^{22}} + \mathbf{Y_{EQk}'}\right)\right]\mathbf{V_{k-1}} - \left[-\mathbf{Y_k^{12}}\left(\mathbf{Y_k^{22}} + \mathbf{Y_{EQk}'}\right)^{-1}\mathbf{I_{EQk}'}\right] \quad (24)$$

The relationship for current and voltage in the combined Norton equivalent models is making it possible to extract directly from (25) the expressions for Y_{EQk} and I_{EQk}.

$$\mathbf{I_k = Y_{EQk} V_{k-1} - I_{EQk}} \quad (25)$$

For the line (26) and (27) cloud be used:

$$\mathbf{Y_{EQk} = Z_k^{-1} + \frac{1}{2} Y_k - Z_k^{-1} \left(Z_k^{-1} + \frac{1}{2} Y_k + Y'_{EQk} \right)^{-1} Z_k^{-1}} \quad (26)$$

$$\mathbf{I_{EQk} = Z_k^{-1} \left(Z_k^{-1} + \frac{1}{2} Y_k + Y'_{EQk} \right)^{-1} I'_{EQk}} \quad (27)$$

For switch (28) and (29) cloud be used:

$$\mathbf{Y_{EQk} = Y'_{EQk}} \quad (28)$$

$$\mathbf{I_{EQk} = I'_{EQk}} \quad (29)$$

For transformer (30) and (31) cloud be used.

$$\mathbf{I_{EQk} = Y_k^{pp} - Y_K^{ps} \left(Y_k^{ss} + Y'_{EQk} \right)^{-1} Y_k^{sp}} \quad (30)$$

$$\mathbf{I_{EQk} = Y_k^{ps} \left(Y_k^{ss} + Y'_{EQk} \right)^{-1} I'_{EQk}} \quad (31)$$

The driving point of the Norton equivalent method is computed from the incoming branch of each bus starting with the most deeply nested sub-laterals and working back toward the main feeder. At each bus the procedure consists of two parts which are:

a) All current sources and admittances connected in parallel to the bus are summed together to give the Norton equivalent of the network that is supplied through that bus.
b) The Norton equivalent is combined with the incoming branch to determine the driving point of the Norton equivalent for that branch.
c) At the end the driving point of the Norton equivalent for the incoming branch of each bus is known.

$$\mathbf{I_k = Y_{EQk} V_{k-1} - I_{EQk}} \quad (32)$$

$$\mathbf{Y_k^{12} V_k = I_k - Y_k^{11} V_{k-1}} \quad (33)$$

The voltage and current at a bus for outgoing branches can be determined from the corresponding driving point equivalent. This procedure involves starting at the source, for which voltage is known followed by the computation of voltages and currents toward the end buses.

The current is computed for the bus with the incoming branch and updating bus voltage. The new value of voltage computed for bus k is directly obtained from the incoming branch of bus k which will lead to updating the value of voltage using Norton equivalent.

For the line (34) cloud be used:

$$\mathbf{V_k = V_{k-1} - Z_k \left(I_k - \frac{1}{2} Y_k V_{k-1} \right)} \quad (34)$$

For switch (35) cloud be used:

$$\mathbf{V_k = V_{k-1}} \quad (35)$$

For transformer (36) cloud be used:

$$\mathbf{V_k = \left(Y_k^{ss} + Y'_{EQk} \right)^{-1} \left(I'_{EQk} - Y_k^{sp} V_{k-1} \right)} \quad (36)$$

5. Conclusions

The independent solar photo-voltaic system is an important and easy method, especially in residential areas that are geographically far from the public electrical network. It is used for heating and lighting operations in schools, hospitals, and other facilities. This system relies on the availability of sunlight in the required location. This paper presents the design of an independent system for running a small isolated house. Based on daily consumption, the capacity of the photovoltaic panels, the size of the battery charge regulator, the size of the battery bank, the inverter, and the connection cables, this paper is useful for designing and installing a photovoltaic system for a specific load with the purpose of replacing the conventional source or providing a permanent source of energy. The power flow algorithms used are particularly the Norton reduction method (N-PARS), which has numerous features that make it exceptionally suited to certain situations. N-PARS is a general method to solve the radial power flow problem that can handle all transformer connection types. The method is efficient for networks that do not contain constant PQ elements. The equivalent circuit parameters themselves, calculated during the solution process, may be suitable for particular applications. Meanwhile, the NR-PARS methods exploit the radial structure of the network. The work required for each iteration is directly proportional to the number of buses. If the number of iterations remains constant, the work grows linearly with the size of the system, making NR-PARS suitable for very large-scale systems.

6. Nomenclature

Table 2. Parameters with their units.

Parameter	Unit	Description
Irs	Amp	Reverse saturation current
Isc	Amp	Short circuit current
Iph	Amp	Photo current

ki	Amp	Short circuit of cell at some particular temp and radiation
I_0	Amp	Module saturation current
I	Amp	Current output of PV module
I_scc	Amp	Solar charge controller
T	Kelvin	Operating temperature
Tn	Kelvin	Nominal temperature
q	coulombs	Electron charge
Voc	volt	Module open circuit voltage
Vt	volt	Diode thermal voltage
V_d	volt	Drop voltage
$V_{dc\text{-}sys}$	volt	System voltage
Ns	-	Number of cells connected in series
Np	-	Number of PV modules connected in parallel
Rsh	ohms	Shunt resistance
Rs	ohms	Series resistance
Rload	ohms	Loas resistance
Ir	W/m^2	Solar irradiation
Ø	degrees(°)	Latitude
δ	degrees(°)	Solar declination
ωs	degrees(°)	Sunset hour angle
E_i	watt-hour	Energy demand per day
P_i	watt	Individual load
Tu	hour	Time of use of load
P_t-pv	watt	Complete size of PV array

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