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DYNAMIC MODELING AND FEASIBILITY ANALYSIS OF LI-ION BATTERY FOR PV APPLICATIONS IN EGYPT

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ABSTRACT

Varity of EES devices provides a widely market for many applications, in the side of on grid, the power system stability is the main corresponding application of EES devices, and on the side of off grid, supplying grid isolated villages is poised to become very important goal. In this paper a proposed dynamic modeling of Li-ion battery is presented. The model is implemented in Simulink to indicate the characteristics of Li-ion battery integrated to a PV system and supplying a constant load. A case study is presented to verify the applicability of the proposed model. In this case study, the system is proposed to supply an isolated village located in Halayeb region in Egypt. The system is composed of PVmodulesconnected to Li-ion battery storage bank to supply the village load. A feasibility study is performed and it indicates that the cost of generated electricity is competitive for this rural area.

Keywords: Li-ion Battery, Dynamic Model, PV, economic analysis, Halayeb.

INTRODUCTION

Battery modelling is promoted to be an important representation of batteries, it is considered as a challenge. There are various battery models which have been proposed in many papers. For any model selection there are multiple choices with different parameters, and there is a trade-off between model complexity, accuracy, and parameterization effort. Barton et al. [1], have proposed the first complete model. In that model, the surface tension was assumed to be one of the driving forces of dendrite propagation, and it could be calculated by its correlation with an over potential term caused by pressure variation inside and outside the dendrite tip. The Brownian statistical simulation model has become a useful approach to simulate the morphology evolution of the deposited species. The Chazalviel electro migration-limited model Developed in 1990s, has described the dendrite initiation induced by an electro deposition process, which was limited by electro migration other than diffusion [2]. Danilov et al. [3] have discussed the ionic conductivity of the organic electrolyte in Li-ion batteries; they illustrated most of characteristics of ionic transportation with realistic examples. Side by side, Danilov et al [4] studied the ionic transportation properties of organic electrolyte in Li-ion batteries, and they also simulated the transient and steady state behavior of the Li-ion battery electrolyte. Hutzenlauba et al. [5] proposed a combination between a three-phase, three-dimensional reconstruction of a $LiCoO_2$ battery cathode based on focused ion-beam/scanning electron microscopy imaging with an electrochemical model. Fotouhi et al. [6] presented a very efficient review on the usage of Lithium batteries from Li-ion to Li-sulfur in electrical vehicles; they also reviewed the models' types and their classifications as: mathematical models, electrochemical models and electrical equivalent circuit models. Electrical equivalent circuit network models (EC), are considered as the common battery modeling methods, especially for Electric Vehicles (EV) applications. It is represented as a less complexity and efficient model, this type of modeling has been used in many applications with various types of batteries.

The purpose of this paper is to present a brief description of the Li-ion battery dynamic modeling. The model is implemented in Matlab/Simulink environment. A case study is presented to verify the applicability of the proposed model. In this case study, the proposed system is composed of PV modules connected to Li-ion battery storage bank, to supply the loads of Egyptian isolated village. A feasibility study is performed and the results are analyzed.

MATHEMATICAL DYNAMIC MODEL OF LI-ION BATTERY

Generally, three categories of models are existent: mathematical models, electrochemical models and electrical equivalent circuit network. Mathematical models are considered as complex models which have much iteration to get an accurate result; furthermore it cares about the internal chemical reactions in the cells which is out of interest. Electrochemical models are depending on the physics-based methods, it works to give information's about the internal dynamics of batteries by a set of coupled partial differential equations. Electrical equivalent circuit network models (EC), are considered as the common battery modeling methods, especially for Electric Vehicles (EV) applications. It is represented as a less complexity and efficient model, this type of modeling has been used in a many applications and various types of batteries. In this paper the dynamic model is used to simulate the Li-ion battery due to many reasons including:

1. It represents the Li-ion battery electrically by the bulk parameters.
2. Its assumptions are not to simplify the calculations but to neglect the chemical reactions.
3. It takes into consideration the battery SOD (State of Charge), SOD (State of Discharge) and battery temperature with constant load.
4. It doesn't need complex logic with iterative methods to represent the battery.

In dynamic model the electrochemical and electro-thermal processes are uniform over the entire battery. Some assumptions should be taken into account, it should ignore all special variations of concentrations, phase distributions and potentials, by this assumption the battery is represented by bulk parameters. The model components which represent this model are:

1) An equilibrium potential E,
2) An internal resistance R_{int}, having two components R_1 and R_2,
3) An effective capacitance C that characterizes the transient response of charge double layers in the porous electrodes.

Figure 1 shows the electrical circuit of these components [9]

The mathematical relations that describe each component and the circuit roles are explained by the following equations. [9]

$$E[i_b(t), T_b(t), t] = V_b[i_b(t), T_b(t), t] - R_{int}\, i_b(t) \quad (1)$$

$$V_b[i_b(t), T_b(t), t] = \sum_{k=0}^{n} c_k . SOD^k[i_b(t), T_b(t), t] + \Delta E(T_b) \quad (2)$$

$$SOD[i_b(t), T_b(t), t] = \frac{1}{Q_r}\int_0^t \alpha[i_b(t)].\beta[T_b(t)].i(t)dt \quad (3)$$

Where:

E	Battery equilibrium potential, V
ΔE	Battery potential correction factor, V
i_b	Battery current, A
T_b	Battery temperature, K
t	Independent variable time, sec
R_{int}	Battery internal resistance (R_1&R_2), Ω
V_b	Battery voltage, V
SOD	State of discharge,
C_k	Coefficient for the k^{th} order term for the polynomial representation of the reference curve and is the battery capacity referred to the cutoff voltage
Q_r	Reference battery capacity, Ah

α Rate factor
β Temperature factor.

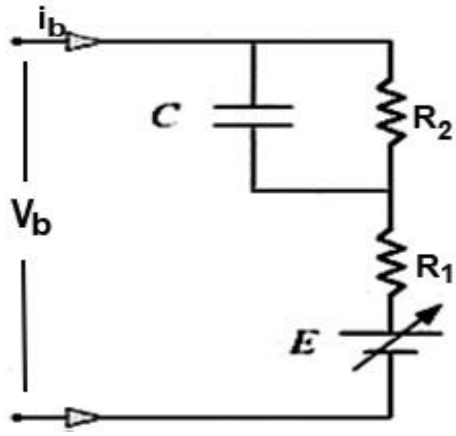

Fig. 1 The electrical dynamic model representation of the Li-ion battery

The last equations can be described as follow: From the basic information, the potential of the battery (OCV) relays on the temperature and the battery materials of the electrodes, which can be represented in terms of SOC, where the discharge capacity of the battery relays on the discharge rate and the temperature [10]. So, the general expression of the potential is a function of battery current i_b , temperature T_b, and the time domain t, $E(i_b, T_b,t)$.

Four steps can be used to formulate the last equations. Firstly, a curve of battery voltage with the depth of discharge is chosen as a reference curve as shown in Fig. 2. The fitted n^{th}-order polynomial curve of that curve is also used in the same figure. Furthermore, the relation of the battery potential as a function of SOD is formulated by excluding some parameters as: internal potential losses, kinetic-limitation, and concentration-limitation resistances.

Secondly,the discharging current of the reference curve is chosen as a reference current (0.7A). The SOD depends on the rate factor, it has a unity value for the reference curve. As the SOD depends on the temperature factor, choosing the temperature factor is the third step. The temperature factor is chosen as unity as it is related to the reference curve. Finally, ΔE is used to compensate for the variation of the equilibrium potential due to the temperature changes. The term ΔE has zero value at the reference temperature. The relation between the rate factor α and the discharge current is indicated in Fig. 3. The effect of the battery temperature on the temperature factor and the potential correction factor are depicted in Figs. 4 and 5 respectively. These characteristic curves are belonging to *Sony US18650* li-ion battery [9].

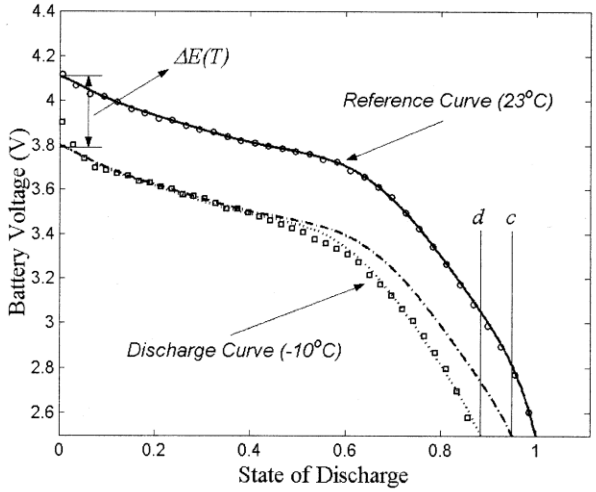

Fig. 2: Reference and discharging curves for li-ion battery with its designing factors.

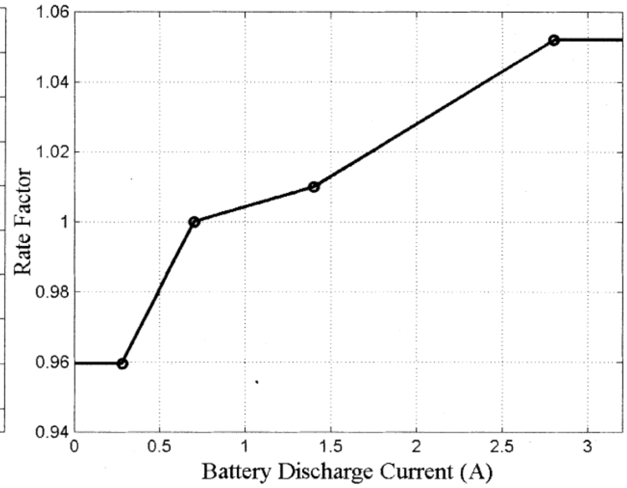

Fig. 3: Rate factorα for li-ion battery (Sony US18650) and reference current is 0.7 A

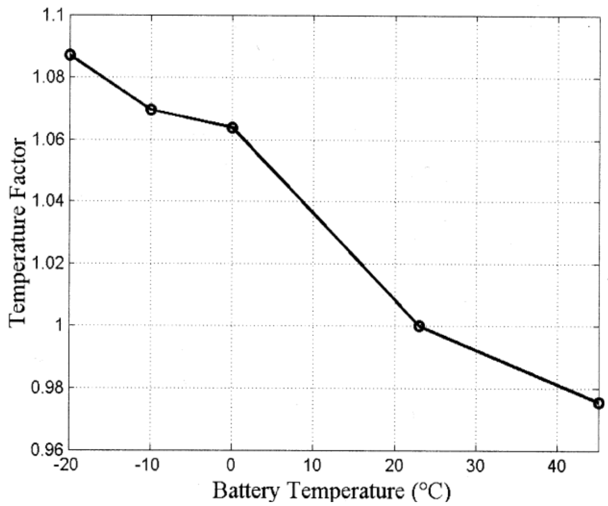

Fig. 4: Temperature factor β for li-ion battery US18650) and reference temperature is 23°C. .US18650). The reference temperature is 23°C

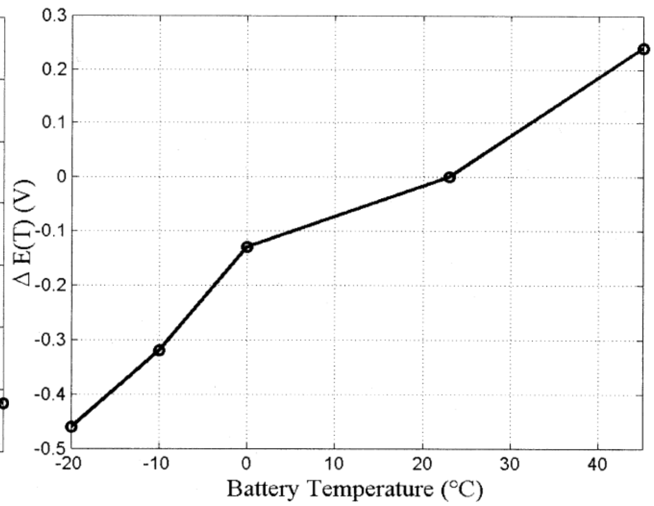

Fig. 5: The potential-correction term in relation (Sony with battery temperature of li-ion battery (Sony

SIMULINK MODELING

A dynamic modeling of Li-ion battery is created in Matlab/Simulink environment. The battery is integrated with a PV system to supply a resistive load. The simulated system is depicted in Fig.6. The PV system is considered as constant DC voltage source (4.5 V). The load is represented as a resistive load (5 ohm) which is connected directly to the battery output.

The dynamic model parameters are represented as: internal resistance R1 and R2, values are 0.08 and 0.04 ohm respectively, internal capacitance (C) a value is 4 F, and the cycle time is 15 seconds. To enhance the battery life time for much healthy energy cycling, the value of SOC is taken as 80% whereas the value of SOD is taken as 15%.The system output voltage during the charging, storing and discharging is shown in Fig 7.

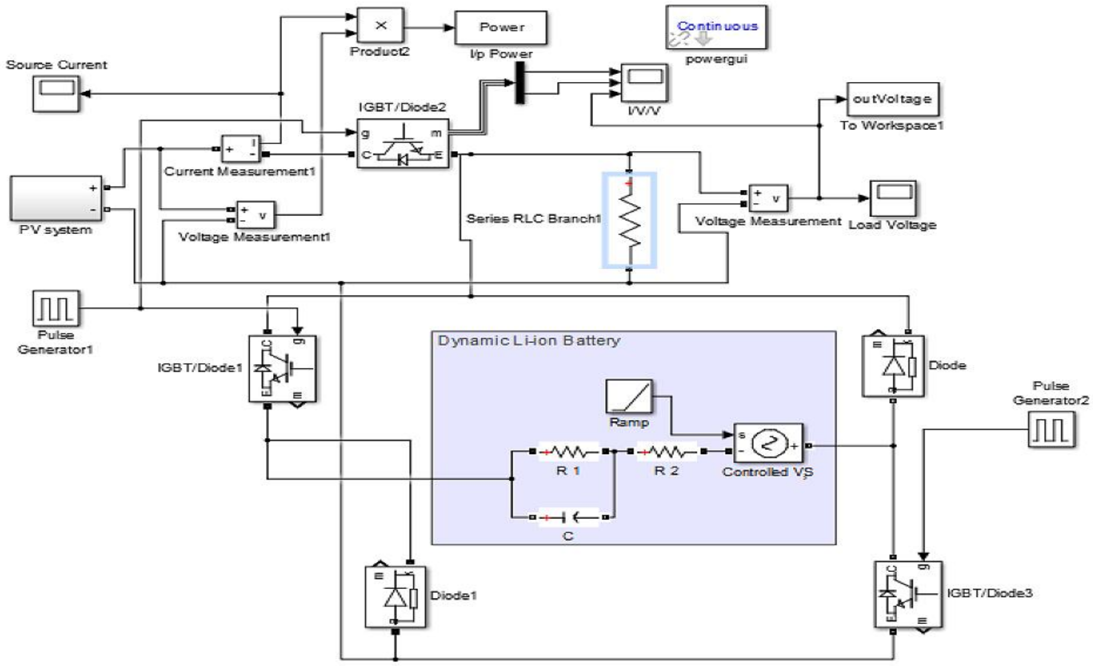

Fig. 6: Dynamic Li-ion Battery modeling with PV source and resistive load

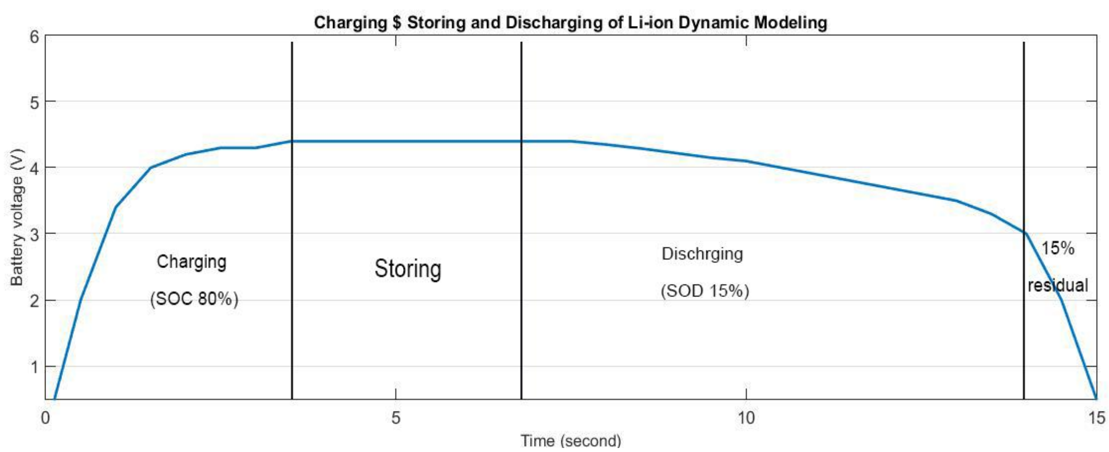

Fig. 7: Charging & Storing and Discharging of Li-ion Dynamic Modeling

The right part of Fig. 7 represents the minimum allowable voltage of Li-ion battery at 15 % SOD; this value is the minimum for long battery life time.

CASE STUDY

Li-ion battery is a preferable choice for PV system applications, besides its high energy density, it also has relatively long operating life time. So, if the application is concerned with stable operation, Li-ion battery is recommended. A case study is proposed with setup design parameters. In this case study, the system is proposed to supply an isolated village located in Halayeb region in Egypt. The system is composed of PV modules connected to Li-ion battery storage bank to supply the village load.

A. Characteristics of the Proposed Site

The system is built up to supply an estimated load in an isolated Egyptian village in Halayeb Triangle in Red Sea Governorate at latitude of 22.03 North and longitude of 36.8 East, with elevation of 12 over sea level. This region is chosen due to many reasons as:

1- Many poor villages in Halayeb region are not connected to the electrical grid.

2- This part is located at far south of Egypt and it is very difficult to provide electricity and other civil service to it.
3- The sun irradiance in this region is very good all over the year and the average energy of the PV output is 1830 KWh/KW_p per year [11].

Figure 8 provides the average sunshine hours per month for Halayeb Triangle. The figure shows that this location has high sunshine hours all over the year. The sunshine reaches 365-370 h/month in the summer and 290-300 h/month in the winter and with total sunshine hours >3870 h/year. [12]

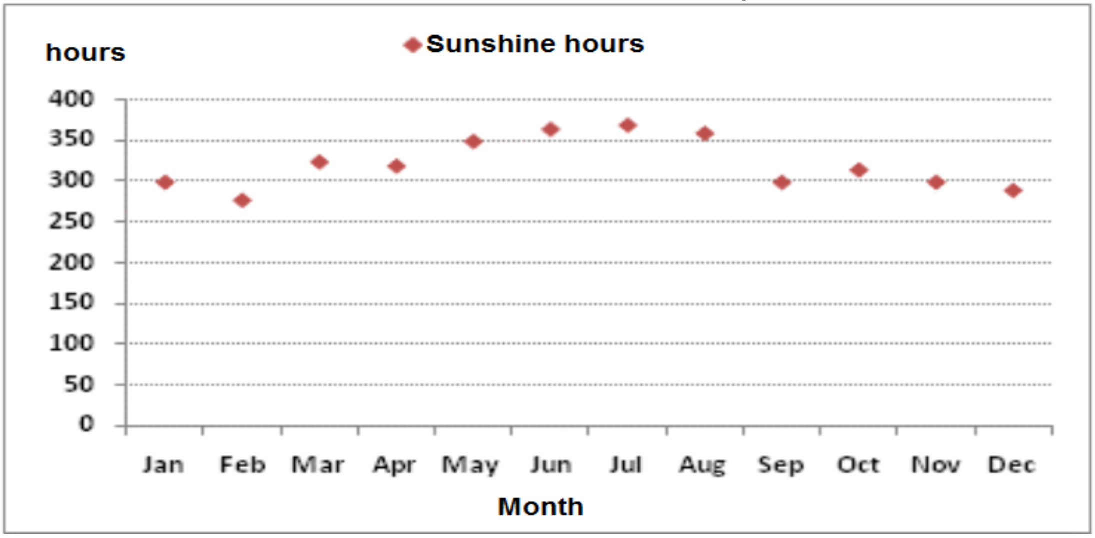

Fig. 8: Monthly mean sunshine hours [12].

In Egypt, the PV solar system must face the south direction of the sun. Any change in the system's azimuth angle (the angle between the normal to the system and the south direction) affects the irradiation values of the solar system. Figure 9 shows instantaneous irradiation of sample days in July and December at the best falling angle for zero azimuth angles for the proposed site. It is concluded from the figure that Halayeb region has higher irradiation values in summer than in winter with a longer duration of daylight in the summer.

The PV placing angle is an important factor for obtaining maximum power. In Halayeb, it has high radiation levels with a yearly average of 7 kWh/m^2/day for 24° tilted facing south system (180^o from North). Therefore, the annual sunshine hours reach 3873 hours/year. [13]

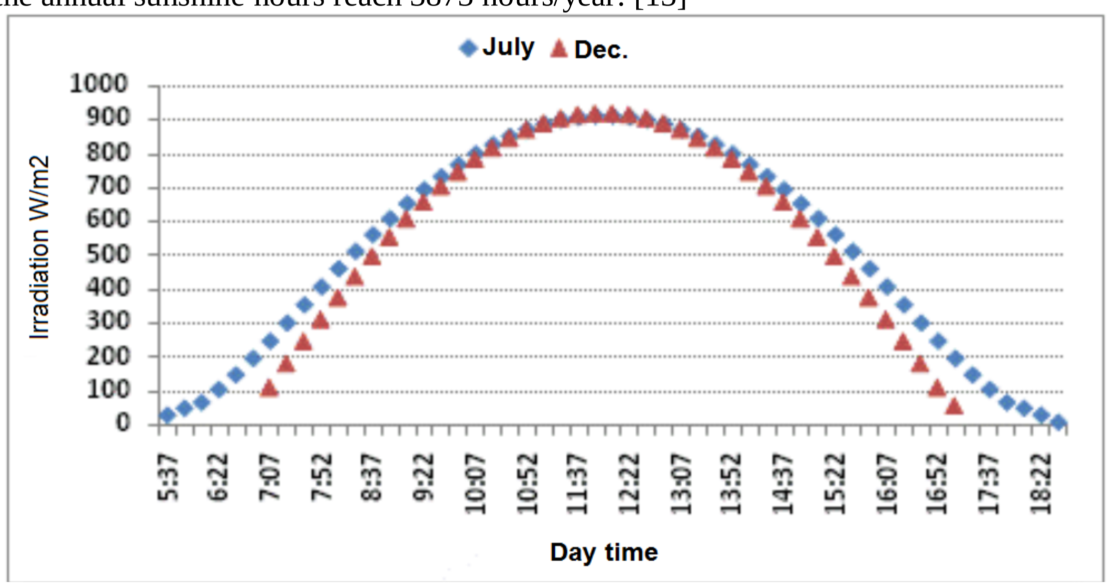

Fig. 9: Instantaneous irradiation of sample days in July and December at optimum tilt angle for Halayeb region [13].

B. Residential Daily Load Requirements

Most rural areas in Egypt consumes low energy as a daily demand. The estimated loads per home and working times are illustrated in Table 1. It is assumed that the rural village consists of 135 similar homes and each home consists of six persons over 50 m^2 area.

TABLE. 1 Estimated loads and their ratings for a rural Egyptian home

Device	Quantity	Unit power (W)	Running time per day	Hours of operation in (h)	Energy required (Wh)
LED lamps	2	7	0 – 5	5	70
LED lamps	1	7	9 - 17	8	56
LED lamps	4	7	17 - 19	2	56
LED lamps	6	7	19 - 22	3	126
LED lamps	2	7	22 - 0	2	28
Refrigerator	1	100	0 - 24	24	600
Fan	2	50	12 - 20	8	800
TV	1	100	14 - 20	6	600
Washing machine	1	200	11 - 12	1	200
Total					2536

In Table 1, the refrigerator works for 24 h with daily consumed energy is 600 Wh, this value represents the actual consumed energy which is calculated from dividing the total time that the refrigerator is plugged in by 4. [14]

The total energy consumption is approximately 2536Wh/day per home (Table 1), therefor the expected total energy consumption for 135 homes is 342 KWh per day. The load profile can be distributed over the day hours by considering that the base load from 0 to 11 am is about 100 W, and the peak loads period is from 11 am to 20 with maximum level 342 W at time 19. Figure 10 shows the estimated load profile of each home.

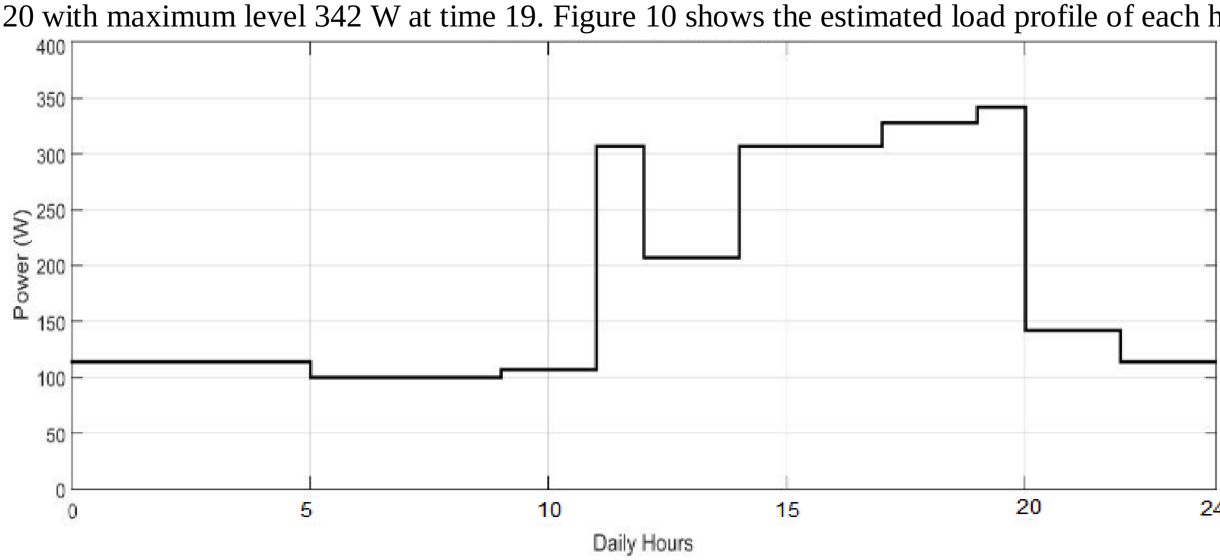

Fig. 10: Daily load curve of an isolated home in a village in Halayeb region, Egypt

C. System Description

The renewable PV system is used to charge Li-ion battery cells to supply a grid isolated domestic load, it is designed to work for 24h daily. The line diagram of the PV system with Li-ion batteries is represented in Fig. 11.

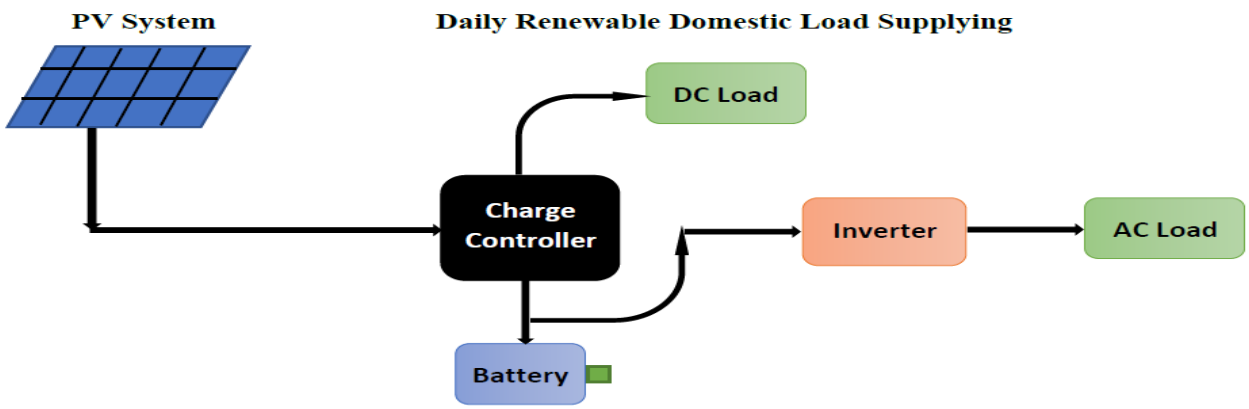

Fig. 11: Daily renewable domestic load supplying

C1. PV Module

The PV size is designed to produce the required energy to supply the prescribed daily houses loads. The PV energy is dependent on the solar irradiance in the region kW/m^2/day. Equations 4 and 5 are used to compute the total PV area required to supply the load and the PV array peak power [13].

$$A_{PV} = \frac{E_L}{H \times T_c \times \eta_{PV} \times \eta_C \times \eta_{INV} \times \eta_B} \quad (4)$$

$$P_{PV} = A_{PV} \times \eta_{PV} \times H_{SC} \quad (5)$$

Where:

A_{PV} : total area of the required PV array, m^2
E_L : required daily load energy for the village, Wh/day
H : total daily solar energy, kWh/m^2/day
T_C : Module temperature coefficient
η_{PV} : PV efficiency
η_C : Controller efficiency (95%)
H_{SC} : standard solar irradiation, (1000 W/m^2)
P_{PV} : the PV array peak power, W
η_B : Battery system efficiency (92%)
η_{INV} : Inverter efficiency 96 %

In this study, the module efficiency is (η_{PV}), about 17.8%.

- Module temperature coefficient is (TC), TC can be taken safely of 0.80 [15].
- The efficiency of the controllerη_C, is 95%.

From equations 4 and 5, the PV area can be calculated for houses loads energy E_L= 342 KWh, and the average solar irradiance is 707 W/m^2/day Fig. 9 and total daily solar energy is 7.02 kWh/m2/day[13].Therefore, the PV area is 407.8 m^2, and its output peak power is 72.6 KW.The required PV panels should be 500 panel to produce rated output power 75 kW with overall cost 30,000$, this panel is chosen as it is efficient and commercial type. The parameters of (KW-SP-150M)Monocrystalline PV type is given in Table 2.

TABLE: 2 Parameters of the (KW-SP-150M)Monocrystalline PV modules

Parameter	**Value**
Maximum power (P_{mp})	150 W
Maximum power voltage (V_{mp})	18.1 V
Maximum power current (I_{mp})	8.34A
Open circuit voltage (V_{oc})	21.6V
Short circuit current (I_{sc})	9.4A
Output tolerance (%)	0 +/- 3%
Efficiency	17.8%
Frame	Clear anodized Aluminum alloy
Junction Box Type	IP65, with bypass diodes
Dimensions	1480*680*40 mm
Weight	10.50 kg/pc

C2. Inverter

The inverter is used to supply the AC loads, its rated power should be larger than the maximum power of the loads by 10-25 %. The chosen inverter model is 5 KW (SPMC481) which is suitable for large applications. The inverter characteristics are shown in Table 3.

TABLE 3: DC – AC inverter specifications

Model	**SPMC481**
Nominal Battery Voltage	48 V DC
Continues Power	5 KW
0.5 hour rating	7 KW
Surge rate (30 second)	12 KW
Continuous charge current	104 A
Peak efficiency	96 %
Operating temperature	-10 : + 60 ^{o} C
Enclosure class	IP 43
Net weight	40 Kg

The system rated load is 342 KWh, therefore the inverter rated power must be much higher than the rated load energy by 20% to overcome the inverter losses and provide a spare capacity. A 90 KW rated inverters capacity must be provided, so for the unit capacity is 5 KW, the needed units are 18 unit. The unit price is approximately 6,500 $, therefore the total cost is 120,000$.

C3. Battery System Model

The battery system is used to store the energy from the PV for using it at nights or at the cloudy hours. The Battery storage Capacity (B_C) can be calculated referring to the battery efficiency, inverter efficiency, Depth of Discharge (DOD), and the numbers of continuous cloudy days (N_C). The DOD is a parameter refers to the battery life time, it has a range from 0:100 %. From the simulated modeling results, the SOD is presented as 15 %, therefor the DOD is 85 % which will enhance the Li-ion battery life time to be 8-10 years. Halayeb region is very sunning region all over the year days, therefore the N_C parameter can be neglected and equals unity. The Li-ion battery storage capacity can be calculated by equation 6 as follows: [13]

$$B_C = \frac{E_L \times N_C}{DOD \times \eta_{INV} \times \eta_B} \quad (6)$$

Where:

E_L : Village loads capacity 342 KWh

N_C : Cloudy days and is neglected

DOD : Depth of Discharge 85 %

η_{INV} : Inverter efficiency 96 %

η_B : Battery efficiency 92 %

From equation 6, the capacity of the battery is 455.6 KWh. Table 4 shows the properties of a single power wall battery package. The prices include the battery package, charger, switches, connections and installing instruments.

TABLE 4: Power wall battery package properties

Propriety	**Value**
Price	138000 $
Capacity	460 kWh
Unit price	Price/Capacity = 300$/kWh
Power	25 kW Continuous , 30 kW peak
Efficiency	92 %
Voltage	200V – 240 V

C4. Charger Controller

The charge controller in a stand-alone PV system is used to improve the life of the storage batteries. It protects the batteries from overcharge which can damage them. Table 5 presents the specifications of the charger controller (MPP SOLAR, PCP4524). It has rated power up to 4.5 KW and rated voltages 12, 24, 48 V.

TABLE 5: Charger controller specifications

Model	**MPP SOLAR, PCP4524**
Rated voltage	12, 24, 48 V
Rated power	Up to 4.5 KW
Solar charge controller	PWM
Maximum current	45 A

The system rated power is 75 KW, therefore it is needed 17 controller unit to provide rated power of 76.5 KW. The price of each unit is 210 $ for the 48 V module, so the total cost is 3570$.

D. Feasibility Analysis

The economic analysis strategy is considered as a guide line to the cost calculation study. Life Cycle Cost (LCC) analysis is represented as the most valuable statistical evaluation tool for the economic behavior of the energy system. It covers the capital cost and initialization stage, moreover operation & maintenance (O&M) and the replacement stage. The capital cost represents the cost for buying all the system components including: PV panels, storage batteries, charger controller, inverters and auxiliaries. The operation and maintenance process is required for stable and long run operation, some tools replacement should be achieved for that purpose. In this system the storage Li-ion batteries can run stably for 8-10 years with suitable SOC and SOD, so the system should be replaces three times over the 25 years life.

The LCC analysis must be performed referring to the longest life component of all system parts. The optimum life cycle of the Monocrystalline silicon modules used is around 25 years which can be taken as the life cycle period for the proposed system. Furthermore, there are two important parameters should be taken into account for future cost estimation, first is the inflation rate and second is the discount rate. According to the Central Bank of Egypt the inflation rate is 12% and the discount rate is 17% in 2018 [16]. The installation cost (I_C) and the annual O&M cost (OM_C) represent 10% and 2% of the PV cost respectively. The yearly O&M costs can be intended depending on the system capital cost taking into consideration the inflation and discount rates, from equation 7 the OM cost is calculated. [13]

$$OM_c = 2\,\%\,PV_c \times \left(\frac{1+i}{1+d}\right)\left[\frac{1-\left(\frac{1+i}{1+d}\right)^n}{1-\left(\frac{1+i}{1+d}\right)}\right] \quad (7)$$

The system's life cycle cost can be calculated by adding the PV, Batteries, charger controller, inverters, installation, and operation & maintenance costs as in equation 8.

LCC = PVc + Bc + INVc + Cc + Ic + OMc (8)

Where:

PVc : PV cost, $
Bc : Batteries cost, $
INVc : Inverters cost, $
Cc : Charger controller cost, $
Ic : Installation cost, $
OMc : operation and maintenance cost, $

As explained before, the costs of the system components for 25 years life time are taken as:

- **Batteries:** the battery package for 460 KWh Li-ions type is 138000$. The package life time is 8-10 years, so it must be replaces three times over the 25 years, therefore the total cost is 414000$.
- **Inverters:** 18 units, 5 KW inverter are used in the system each costs 6500$ and the overall costs is 120000 $.
- **Charger Controller:** it is needed 17 controller unit to provide rated power of 76.5 KW. The price of each unit is 210 $ for the 48 V modules, so the total cost is 3570$.

The annual life cycle cost (ALCC) can be computed using equation 9. [17] The unit electrical cost (UC) in $/kWh can be computed from the annual life cycle cost and the annual energy generated by the PV system by equation 10.[18]

$$ALCC = LCC\left[\frac{1-\left(\frac{1+i}{1+d}\right)}{1-\left(\frac{1+i}{1+d}\right)^n}\right] \quad (9)$$

$$UC = \frac{ALCC}{365 \times E_L} \quad (10)$$

From the last calculations and data, the device costs can be obtained as in Table 6

TABLE: 6 Cost analysis result of the proposed Li-ion Battery storage system for Halayeb village

Device	**Cost ($)**
PV	30,000
Charger controller	3570
Inverter	120,000
Battery package	414,000
O&M cost	7524
Installation cost	3000
LCC	578094
ALCC	43795
UC	0.35

The suggested case study is to indicate the ability of Li-ion battery system to supply a grid isolated village in Halayeb on a small-scale size. The fixed cost of the proposed system can be generally obtained to be 578094$ and the unit cost is 0.35 $ with long life time which reaches about 25 years by regular maintenance.

CONCLUSION

EES devices are the future trend to the world power stability, they are not only solving the problems of daily energy sharing but they also help in power system stability and reliability. Li-ion battery is a new promising battery type used for portable applications especially with compact devices. In this paper, different electrical models of Li-ion batteries were compared. A proposed dynamic modeling of Li-ion battery was presented. The model was built and performed in Matlab/Simulink environment to indicate the charging, storing and discharging characteristics of the proposed model. A detailed case study was implemented based on the dynamic model to supply Halayeb village from PV source. The PV rated energy was 380 kWh and the backup battery system had energy capacity of 460KWh. The overall system efficiency was about 92 % which could help in supplying the appropriated village load (342 kWh/ day). The system life time was suggested for 25 years operation with three times batteries package replacing. A feasibility study was performed and showed that the system overall cost over 25 years was about 578094$, whereas, the unit cost of the produces energy was about 0.35$ respectively.

REFERENCES

1. J. Barton, J. Bockris, "The electrolytic growth of dendrites from ionic solutions." Proceedings of the. Royal SocietyVolume 268, Issue 1335, August 1962, pp.485-505.
2. Z. Li, J. Huang, B. Yann Liaw, V. Metzler and J. Zhang, "A review of lithium deposition in lithium-ion and lithium metal secondary batteries", *Journal of Power Sources*, vol. 254, pp. 168-182, 2014.
3. E. Danilov, P. H. Notten "Mathematical modelling of ionic transport in the electrolyte of Li-ion batteries", Electrochimica Acta, Vol. 53, Issue 17, 1 July 2008, pp. 5569-5578
4. D. Danilov, P. H. Notten "Li-ion electrolyte modeling: The impact of adding supportive salts" Journal of Power Sources, Volume 189, Issue 1, 1 April 2009, pp. 303-308
5. T. Hutzenlauba et. al., "Three-dimensional electrochemical Li-ion battery modelling featuring a focused ion-beam/scanning electron microscopy based three-phase reconstruction of a LiCoO2 cathode", Electrochimica Acta, Volume 115, 1 January 2014, pp. 131-139
6. A. Fotouhi et al. "A Review on Electric Vehicle Battery Modelling: from Lithium-ion toward Lithium-Sulfur", Renewable and sustainable Energy Review, Volume 56, April 2016, pp. 1008-1021.
7. T. Marc, B.Oliver, U.S. Dirk, “Development of a voltage-behavior model for NiMH batteries using an impedance-based modeling concept”. J. Power Sources 2008, vol. 175, pp. 635-643.
8. H. He, R. Xiong, J. Fan. “Evaluation of Lithium-Ion Battery Equivalent Circuit Models for State of Charge Estimation by an Experimental Approach”. Energies, vol. 4, pp. 582-598. , 2011
9. Lijun Gao et al, “Dynamic Lithium-Ion Battery Model for System Simulation”, *IEEETransactions On Components and Packaging Technologies,* vol. 25, no. 3, September 2002
10. HaoSun,et al. "Hard carbon/lithium composite anode materials for Li-ion batteries", Electrochimica Acta, Volume 52, Issue 13, 20 March 2007, pp. 4312-4316
11. “Global Solar Atlas",*Globalsolaratlas.info*, 2018. [Online]. Available: http://globalsolaratlas.info/. [Accessed: 26- Jun- 2018].
12. *https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Aswan,Egypt* [Accessed: 22- Jul- 2018].
13. E. T. El Shenawy. et, al. “Design and Optimization of Stand-alone PV System for Egyptian Rural Communities”. *National Research Centre, Solar Energy Department, El Behouth St., Dokki, Giza, Egypt.* Volume 12, Number 20 (2017) pp. 10433-10446.
14. J. Cofré-Toledo, D. Vasco, C. Isaza-Roldán and J. Tangarife, "Evaluation of an integrated household refrigerator evaporator with two eutectic phase-change materials", *International Journal of Refrigeration*, 2018.
15. N. Agarwal and A. Kumar, Optimization of grid independent hybrid PV–diesel–battery system for power generation in remote villages of Uttar Pradesh, India, *Energy for Sustainable Development*17 (2013) 210-219.
16. "Discount Rates", *Cbe.org.eg*, 2018. [Online]. Available:
17. http://www.cbe.org.eg/en/EconomicResearch/Statistics/Pages/DiscountRates.aspx. [Accessed: 22- Jul- 2018].
18. A. Ghafoor and A. Munir, Design and economics analysis of an off-grid PV system for household electrification, Renewable *and Sustainable Energy Reviews*42 (2015) 496-502
19. E. Tarigan and L. Purba, Assessment of PV power generation for household in Surabaya using solar GIS–PV Planner simulation, *Energy Procedia*47 (2014) 85-93.