International Journal of Digital Information and Wireless Communications (IJDIWC) 8(2): 96-100
The Society of Digital Information and Wireless Communications, 2018 ISSN: 2225-658X (Online); ISSN 2412-6551 (Print)

Hybrid Power Generation: Thermal Power and Photovoltaic Units in Lebanon

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Abstract—Over the years, researches have been focused on different technological strategies to meet up with the increasing demand for high quality and reliable power supply. Prominent of these researches is electrical energy conservation and management. The objective of this paper is to find a relationship and equation that may relate between the demand loads and the required capacity of a thermal power station according to the generated power of a Photovoltaic (PV) of a farm. The resulting equation will help to find the optimum values of power capacities generated by the gen-set according to the generated power by the centralized PV system that varies up and down in terms of solar irradiance curve. An example is taken for one day of June (6 am to 12 pm) in Baalbak-Hermel region of Lebanon.

Keywords—Photovoltaic, Economic Dispatch, Demand Load, Thermal Power Units, Generated Power

I. INTRODUCTION TOWARDS HYBRID POWER GENERATION (THERMAL + PV)

The economic and environmental problems in the power generation have received considerable attention. The apparition of the energy crisis and the excessive increase of the consumption have obliged production companies to implant renewable sources. However, this production poses many technical problems for their integration in the electric system.

FIG I POWER PLANTS IN LEBANON

Lebanon relies essentially on oil imports as its main resource for energy production through thermal power plants as shown in Fig I. During the 2010 baseline year, the total fuel imports to Lebanon (liquid gas, gasoline, gas oil, fuel oil, kerosene, and asphalt) amount to approximately 5,768 ktoe (5,768,269.94 toe) and are consumed in the different sectors in Lebanon. In terms of electricity, the average available electricity production capacity in 2009 (including imports) was 1,500 megawatts (MW) while the average demand was 2,000–2,100 MW. The instantaneous peak demand in the summer of 2009 was estimated at 2,450 MW. The total energy demand in 2009 was 15,000 gigawatt-hours (GWh) although the total produced energy (including imports) was 11,522 GWh. Accordingly; the electric energy deficit in Lebanon was estimated to be 3,478 GWh. In addition to the deficit in electricity supply, the Lebanese electricity sector was facing several problems such as load shedding, technical losses, and the aging of power plants. This situation resulted in technical and financial impacts on customers, the Government, and the entire economy. The Lebanese end-users were forced to rely on diesel generators to overcome the electricity shortages.

There is currently only one PV farm in Lebanon (BRSS) with a capacity of 1 MW and directly connected to the electricity network. Another demonstration project of 1 MW developed in the Zahrani Oil Installations in South Lebanon is connected to the internal network of the Zahrani Oil Installations and feeds the electricity network through the net-metering scheme. The private sector could intervene to build large solar PV farms. The realistic scenario considers that approximately 120 MW of solar installations could be done by the private sector, with the possibility to be increased to 180 MW.

Since most regions of Lebanon offer high solar potential, solar PV installations could be divided according to the following approach:

- Mount Lebanon: 30 to 45 MW
- North and Akkar: 30 to 45 MW
- South and Nabatieh: 30 to 45 MW
- Bekaa and Hermel: 30 to 45 MW

II. ECONOMIC DISPATCH

Economic dispatch (ED) is the calculation of the lowest-cost generation dispatch for a set of generators that is constrained within the individual generator limits and results in a total

generation that equals the total load plus losses [1]. The ED calculation ignores the specific details of the network that the generators are connected to and lumps all the network effects into the losses and total load demand. As a result, the ED calculation ignores the effect that the dispatch of generation has on the loading of transmission branches or the effect it has on bus voltages. The dispatch of generation does, in fact, have an important effect on transmission flows, and under some circumstances these affects need to be taken into account.
The optimal power flow (OPF), as the name implies, couples the ED calculation with a power flow calculation [2] so that the ED and the power flow are solved simultaneously. The total losses of the power system are simply part of the power flow calculation and are reflected in the loading of the generation on the reference bus thus, there is no need to specifically calculate the losses since they are inherently a part of the power flow. More importantly, the ED can be constrained to meet transmission system limits such as MW or MVA flow limits on lines or transformers or voltage limits on buses. The result is the generation dispatch representing the minimum \$/h total generation cost and that also solves the power flow at that optimum.

In the ED calculation, we solve the following problem:

• Objective function = total generation cost in \$/h.

• Each generator is within its minimum and maximum limits.

• Sum of all generator outputs = total load plus losses [3].

Objective function:

$$\min \sum_{j=1}^{N_{gen}} F_j(P_{gen\ j}) \quad (1)$$

Where j is an index over the generators only.

Generator limit inequality constraints:

$$P_{gen\ j}^{min} \le P_{gen\ j} \le P_{gen\ j}^{max},\ for\ j = 1 \ldots N_{gen} \quad (2)$$

Generation, load, loss balance equality constraint:

$$P_{total\ load} + P_{totla\ loss} - \sum_{j=1}^{N_{gen}} P_{gen\ j} = 0 \quad (3)$$

Where N_{gen} is the number of generators

We can write the ED problem as follows:

$$\min f(P_{gen}, u) \quad (4)$$

$$P_{gen} = \begin{bmatrix} P_{gen\ 1} \\ \cdots \\ P_{gen\ NG} \end{bmatrix} \quad (5)$$

and $f(P_{gen}, u) = \sum_{j=1}^{N_{gen}} F_j(P_{gen\ j})$ (6)

III. PV SYSTEM DEFINITION-COMPONENTS AND CALCULATION

A photovoltaic power station, also known as a solar farm, is a large-scale PV system, intended for the supply of merchant power into the electricity grid (FIG. II, FIG. III). The solar power source is via photovoltaic modules that convert light directly to electricity.

PV arrays must be mounted on a stable, durable structure that can support the array and withstand wind, rain, hail, and corrosion over decades. These structures tilt the PV array at a fixed angle determined by the local latitude, orientation of the structure, and electrical load requirements. To obtain the highest annual energy output, modules in the northern hemisphere are pointed due south and inclined at an angle equal to the local latitude.

Inverters are used to convert the direct current (DC) electricity generated by solar photovoltaic modules into alternating current (AC) electricity, which is used for local transmission of electricity, as well as most appliances in our homes. PV systems either have one inverter that converts the electricity generated by all of the modules, or micro-inverters that are attached to each individual module.

FIG. II SOLAR FARM

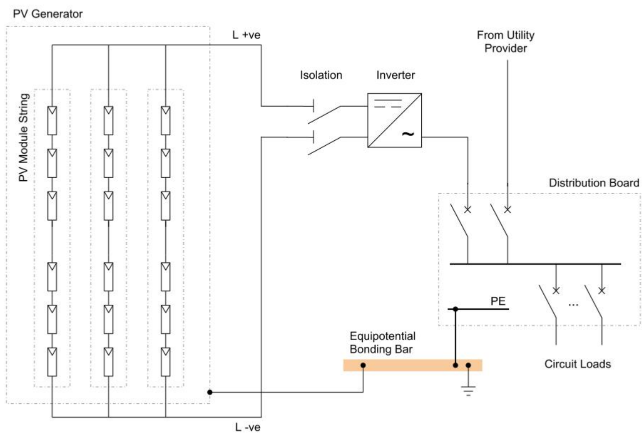

FIG III PV SYSTEM SINGLE LINE DIAGRAM

The global formula to estimate the electricity generated in output of a PV system is [5, 12]:

$$E = A * r * H * PR \quad (13)$$

Where,

E =Energy (kWh)

A =Total solar panel Area (m²)

r = solar panel yield or efficiency (%)

H = Annual average solar radiation on tilted panels (shadings not included)

PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)

r is the yield of the solar panel given by the ratio : electrical power (in kWp) of one solar panel divided by the area of one panel. Example: the solar panel yield of a PV module of 250 Wp with an area of 1.6 m² is 15.6%.Be aware that this nominal ratio is given for standard test conditions (STC): radiation=1000 W/m², cell temperature=25 °C, Wind speed=1 m/s, AM=1.5.The unit of the nominal power of the PV panel in these conditions is called "Watt-peak"
(Wp or kWp=1000Wp or MWp=1000000Wp).

H is the annual average solar radiation on tilted panels, between 200 kWh/m².y (Norway) and 2600 kWh/m².y (Saudi Arabia). You can find this global radiation value here: You have to find the global annual irradiation incident on your PV panels with your specific inclination (slope, tilt) and orientation (azimuth).
PR: PR (Performance Ratio) is a very important value [6] to evaluate the quality of a PV installation because it gives the performance of the installation independently of the orientation, inclination of the panel. It includes all losses.

IV. Formulation of Power Generated by the Centralized PV System

Solar energy is energy produced by the solar radiation, directly or in a diffuse way through the atmosphere. Thanks to various processes, it can be transformed into another form of useful energy for the human activity, in particular in electricity.
Considering TABLE I of weather data from metronome of Baalbalk during the first day of June the irradiance (Kj/hr.m²).

TABLE I. Solar radiation G (Kj/h.m2) for Baalbak-Hermel (1st June)

Time	6AM	7AM	8AM	9AM	10AM	11AM	12AM
G	9.53	202.55	508.47	1217.28	1898.49	2433.81	2799.78
Time	1PM	2PM	3PM	4PM	5PM	6PM	
G	2935.49	2867.6	2569.03	2042.23	1417.97	702.47	

The variation is plotted with the corresponding convex equation as function of time as shown in Fig. IV.

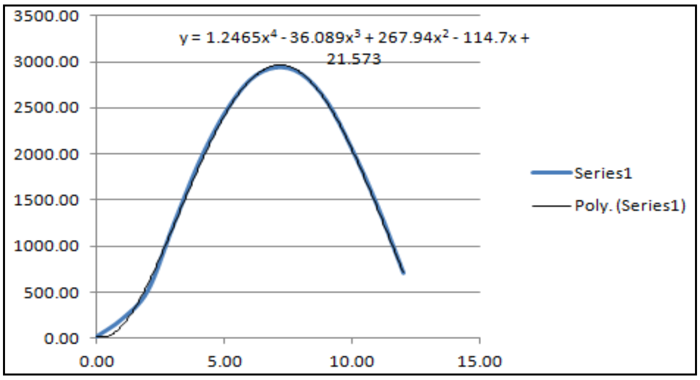

Fig. IV Daily Solar Irradiance for Baalbak-Hermel (1st. June)

The approximation of the curve is polynomial of fourth order. So from 6 am to 12 pm, the curve, Fig. V, is assimilated to a convex function of second order as shown in the figure and looks like the form of power generation of convex function of second order.

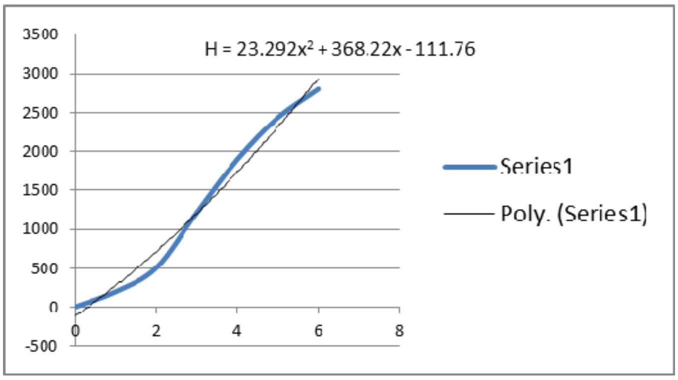

Fig. V Solar radiation of Baalbak-Hermel from 6 am to 12 pm

In this case, we can combine the two systems (thermal and PV) to reach the optimum power flow direction through the determination of the economic dispatch of combined system

V. Case study

Assuming a centralized PV farm station to be built in Baalbak-Hermel region of 15 MW, and assuming that the city is fed by two lines from utility grid power station with maximum capacity of 70MW and from the PV farm.

And The forecasted demand load of the city is as shown in the Fig V.

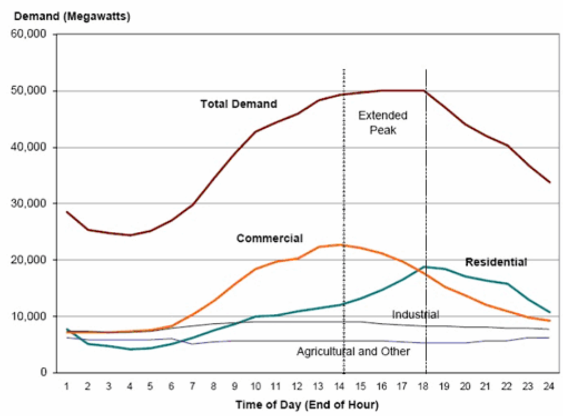

FIGURE VI THE ANALOG DAILY DEMAND LOAD OF BAALBACK CITY

TABLE II. DEMAND LOAD (MW) FROM 6 AM TO 12 PM

Time	6-7	7-8	8-9	9-10	10-11	11-12
Sequence	0	1	2	3	4	5
Demand Load (MW)	28	31	34	38	42	47

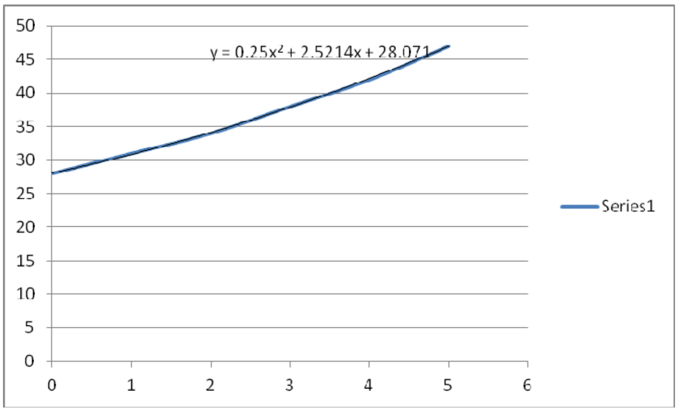

FIG. VII DEMAND LOAD (MW) FROM 6 AM TO 12 PM

The equation of the demand load is approximately given by (from curve):

$P_{Load} = 0.25\ X^2 + 2.5214\ X + 28.07$ MW (function of time) (14)

The equation of energy produced by PV (between 6am and 12 pm is:

$E(x) = A * r * H(x) * Pr$ (13)

Where,

$H(x) = 23.29x^2 + 368.2x - 111.76$ Kwh/m^2 (15)

A = 96,000m^2 (net area of all PV arrays)

r = 98%

PR = 75%

Then,

$E(x) = 1.64x^2 + 25.98x - 7.88$ MWh (16)

As the duration is T=6h, then the equation for one hour is:

$PV(x) = 0.27x^2 + 4.33x - 1.31$ MW (17)

So, from equations (15) and (17), we can find the equation and can forecast how much power we should generate by the thermal unit where:

$Pg = P_{Load} - PV = 0.25\ X^2 + 2.5214\ X + 28.07 - (0.27x^2 + 4.33x - 1.31)$

$Pg = -0.02X^2 - 1.8\ X + 29.38$ MW (19)

This is in the form of parabolic function, as shown in FIG. VIII.

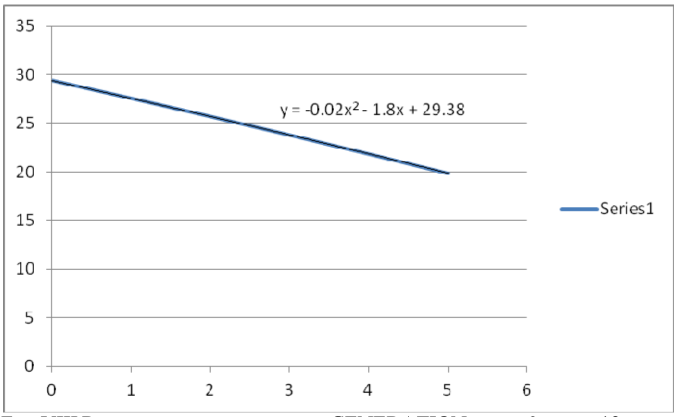

FIG. VIII REQUIRED THERMAL POWER GENERATION FROM 6 AM TO 12 PM

VI. DISCUSSION

Comparing FIG. VII (Demand load) with the FIG. VIII of thermal power generation, it is clear that the curve is changed from convex shape to concave shape which is an advantage in terms of reducing the required power capacity from thermal units during the first part of the day. in the second part of the day while sunset period, the case is reversed (PV generation decrease while load begin to decrease also. in this case the curve of thermal units tends to be approximately constant.

VII. CONCLUSION

Reducing, or “shaving,” peak power demand, reduces strains on the power grid. By intelligently storing electrical energy generated by clean, renewable energy sources such as solar PV systems. Through this paper, we could find an equation for the demand load as function of time. This equation relates the thermal power generation with PV generation and that gives advantages to minimize the size of thermal power station that feeds the city. And comparing to other authors [8,9], instead of storing the energy, we used it in the day time with maximum integration with power generated by thermal station (reducing power) while at night time we increase the production of power according to the demand which will be lower than that of day time. The power generation formula is derived for one part of the day and could be mirror for the second part of the day (12pm to 6pm) where the load decreases and PV generation start to decrease. In the same sequence, we could find the general formula for each region and each day of the year.

Acknowledgment

The author would like to thank the Lebanese international university research team for their support.

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