Microgrid Environmental Impact

Salem Al-Agtash[1], Mohammad Al-Hashem[1], Mohanad Batarseh[1], Angelina D. Bintoudi[2], Apostolos C. Tsolakis[2], Dimitrios Tzovaras[2], Jose Martinez-Ramos[3], Ahmet Onen[4], Brian Azzopardi[5], Lenos Hadjidemetriou[6], Lazaros Zacharia[6], Nis Martensen[7], Mounir Khiat[8]

[1]Department of Computer Engineering, German Jordanian University, Amman, Jordan
[2]Information Technologies Institute, Center for Research & Technology Hellas, Thessaloniki, Greece
[3]Department of Electrical Engineering, Universidad de Sevilla, Seville, Spain
[4]Department of Electrical and Electronics Engineering, Abdullah Gul University, Kayseri, Turkey
[5]MCAST, Triq Kordin, Malta
[6]KIOS Research Center of Excellence, University of Cyprus, Nicosia, Cyprus
[7]Energynautics GmbH, Darmstadt, Germany
[8]Département de génie électrique, ENP d'ORAN, Oran, Algeria

***Abstract*— Power plants have bad impacts on the environment. One of these impacts is Carbon Dioxide (CO_2) emission resulted from power plants that depend on fossil fuel, oil and natural gas. Renewable energy is considered as an important solution for this problem since it is classified as clean and environmentally friendly source of energy and helps reducing the dependency on conventional power plants. High renewable energy penetration into power systems is a big challenge that can be solved by deploying the concept of smart Micro-Grids. This paper presents a study on how much reduction of CO_2 emission can be resulted from deploying smart micro-grid concept on a university campus, German Jordanian University (GJU) campus was taken as a pilot. The micro-grid is meant to operate according to an optimum resource scheduling framework that guarantee a minimum operational cost while achieving high local power availability.**

Keywords— Micro-grids, renewable energy, optimum scheduling, emissions, CO_2 footprint.

I. Introduction

carbon Dioxide (CO2) emissions resulting from power plants have a major environmental impact. It is one of the greenhouse gases that play a significant role in many environmental problems such as climate change and global warming. As a matter of fact, high CO2 emissions is an indicator for air pollution which may result in sever health consequences. A universal agreement exists today on CO2 emissions limits. As a result, many countries have setup their own plans, rules, and policies to mitigate CO2 emissions, mainly by reducing dependence on conventional power plants and switching to renewable energy resources. Authors in [1] and [2] presented important benefits of solar energy in reducing emissions of greenhouse gases such as COx and NOx. It has been shown that a wide use of Photovoltaic (PV) systems can reduce 69-100 million tons of CO2 emissions.

Bhaskara and Chowdhury [3] present a reduction of 2461 kg of annual CO2 emission when generating PV power to cover 68% of its 120-kWh daily consumption. Although, renewable energy resources contribute largely to the reduction of emissions, their penetration is still limited mainly due to the fact that the output power from renewable resources is intermittent [4-6]. Storage systems, demand side management, and use of smart technologies represent prominent solutions to address this challenge [7].

This paper presents a smart microgrid with a substantial reduction of CO2 emissions. The main objective of the designed objective function comprised to operational cost minimization, while meeting constraints of different sorts. The microgrid of the German Jordanian University (GJU) is used for illustration. The generation resources of the microgrid are: Photovoltaic system and Diesel generators as well as its connection to the utility grid. Since manufacturing of the PV panels also result in CO2 emissions, net metering of CO2 emission is used for PV energy.

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II. Micro-grid System

Micro-grids generally consist of renewable generation resources and variety of load profiles that are managed and operated in real-time either in a grid-connected mode or islanded mode.

A. Renewable generation

Renewable generation consists of solar and wind and are complemented by on-site diesel generators and energy storage batteries, which are generally expensive to install and their lifetime is short.

1) Solar power

Solar power is produced by large array of photovoltaic cells, formally defined as,[8]:

$$P_{pv}=\eta AG\left(1-\alpha(T-25)\right) \quad (1)$$

Where G, T, A, η, and α denote solar radiation, ambient temperature, area of panels, system efficiency, and power degradation, respectively.

2) Wind Power

Wind power is produced by converting the kinetic energy of wind turbines, formally defined as, [11]:

$$P_w = \frac{1}{2}\sigma A_b v^3 \quad (2)$$

Where σ, A_b, and v denote air density, swept area of rotor blade, and wind speed, respectively.

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3) Diesel Generators

Since the output power of solar and wind is intermittent and non-controllable, it is necessary to have storage and/or controllable generation in the micro-grid that can replace power shortage and maintain constant local power. The output power of *N* diesel generators is formally defined as:

$$P_G(t) = \sum_{i=1}^{N} P_{Gi}(t) \qquad (3)$$

Where $P_{Gi}(t)$ denotes the output power of the i^{th} diesel generator at time *t*.

B. Scheduling Framework

The micro-grid is meant to provide an optimum scheduling of resources to meet power demand according to a pre-defined local power availability level. local power availability level is denoted as Lav at time t by controlling the power absorbed from the utility grid, and is formally defined by:

$$Lav\ (t) = (1 - fav\ (t)) \times 100\% \qquad (4)$$

Where $Lav\ (t)$ defines the ratio of the grid imported/ exported power ($P_{Gr}(t)$) and the power demand ($P_D(t)$) at time t formally given by:

$$fav\ (t) = \frac{P_{Gr}(t)}{P_D(t)} \qquad (5)$$

Where $P_D(t)$ denotes the demand power of the university campus. Therefore, the required power from diesel generators $P_G(t)$ to achieve the local power availability level is given as follows:

$$P_G(t) = P_D(t) - P_{pv}(t) - P_{Gr}(t) \qquad (6)$$

Where $P_{Gr}(t)$ defines the power absorbed from the utility grid. The optimization problem is then to minimize the total cost of power generation, while meeting micro-grid operating constraints, and is formally given by:

$$\min_{P_{Gi}(t)} C_{GT}\left(P_{Gi}(t)\right) \qquad (7)$$

The operating constraints are Generation – Load balance, desired local power availability, and generation power limits for each generator which can be defined as defined as follows:

$$P_G(t) = P_D(t) - P_{pv}(t) - P_{Gr}(t) \qquad (8)$$

Solving (7) is a generic simplified unit commitment and economic dispatch problem. Augmented Lagrangian approach [10] was used to solve the optimization problem to find the optimal power generation for a given local power availability.

III. GJU Campus

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The proposed scheduling approach will be implemented on GJU campus as a pilot. The campus of GJU consists of 16 buildings. Point of common coupling between the university and the utility grid is located in a main station at the south of the campus. The main station contains two 33/11 kV transformers. Each one of these transformers feeds a group of three 11/0.4 kV transformers located around the campus feeding all the buildings as shown in Fig. 1. These two groups of transformers are connected to each other with a ring configuration via a circuit breaker between transformers (1) and (6) to support the reliability and flexibility of the system.

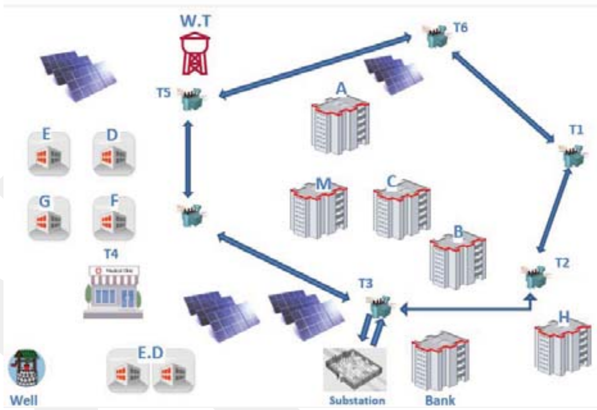

Fig. 1 Distribution of GJU Buildings and Electrical Network

Local power generation, in GJU case, comes from the 2.1 MWp PV system and two diesel generators (700, 350 kVA) while the utility grid is considered as an external generation resource. For this purpose, real data from power demand and PV generation are collected every 5 minutes during year 2016. Fig. 2 shows the average power demand for working days in each month and the corresponding average PV Generation.

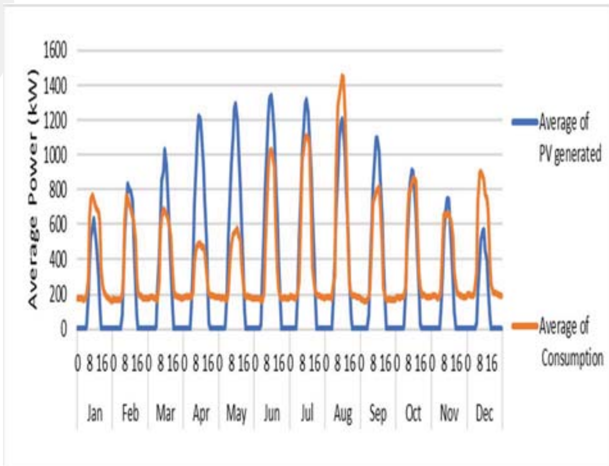

Fig. 2 GJU average power demand and PV generation profiles during 2016

The power of the diesel generator is economically dispatched on two diesel generators, with 350 kVA and 700 kVA capacities. The objective function, therefore, represents the total running cost of the turned-on diesel generators and given by [11-12]:

$$C_{GT}\left(P_{Gi}(t)\right) = 0.0001 * (P_{G1}(t))^2 + 0.1756 * P_{G1}(t) + 0.0001 * (P_{G2}(t))^2 + 0.2181 * P_{G2}(t) + 25.3235 \quad (9)$$

IV. Analysis and Results

CO_2 emissions was calculated for both no micro-grid and micro-grid scenarios at GJU. In the no micro-grid scenario, the whole power demand is being supplied by the utility grid. Accordingly, the emissions are calculated by multiplying the monthly energy consumption by constant emission coefficient. Table [1] shows different types of fossil fuel and the corresponding CO_2 emissions resulted from each one of them. Since around 90% of electricity production in Jordan in 2016 was supplied by natural gas power plants as shown in Fig.3, the value of 0.55 kg of CO_2 per kWh was taken for GJU case.

Table 1. CO_2 emissions per KWh production for different types of nonrenewable sources [13]

Fuel	Pounds of CO2 per million Btu	Heat rate (Btu per kWh)	Pounds of CO2 per kWh
Coal			
Bituminous	205.691	10,080	2.07
Subbituminous	214.289	10,080	2.16
Lignite	215.392	10,080	2.17
Natural gas	116.999	10,408	1.22
Distillate oil (No. 2)	161.290	10,156	1.64
Residual oil (No. 6)	173.702	10,156	1.76

Last updated: February 29, 2016

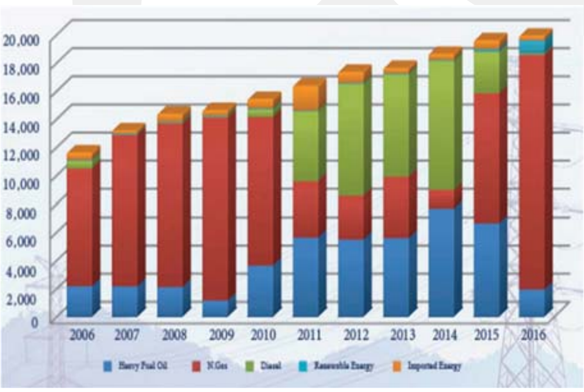

Fig. 3 Yearly Variation of Fuel Type Used in Jordan to Produce Electricity [14]

In a micro-grid scenario, the same process is made taking into consideration that the emission coefficient value varies depending on generation resource which the electricity is supplied from which in GJU case are utility grid, PV system and diesel generators. The emission coefficient value for the diesel generator energy is 2.6 (kg/liter) [15] while for the PV energy it equals to 0.05 kg of CO_2 per kWh since manufacturing of PV system result in greenhouse gas emissions [16].

Fig.4 shows a monthly comparison between CO2 emission in both normal no micro-grid and micro-grid scenarios assuming 50% local power availability . Negative values in April and May are due to the excess of PV generation being sold to the utility grid. This has resulted in reducing the use of conventional power plants. As a result, the annual CO_2 emissions in the normal operation is 1734 kT. While during micro-grid operation it equals to 488 kT of CO_2, hence a total of 1246 kT of CO_2 annual saving.

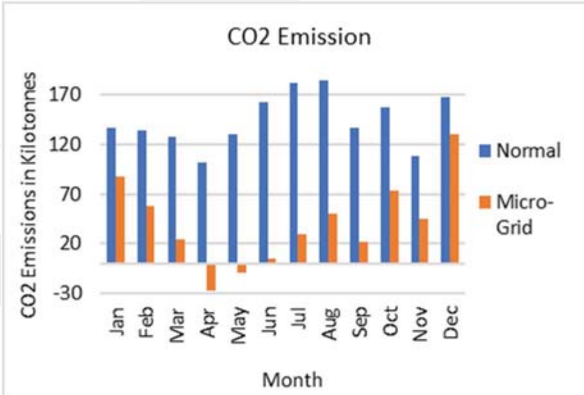

Fig. 4 Monthly Comparison between Resulted CO2 Emission Normal and Micro-Grid Operation

Fig.5 shows the variation of average CO_2 emissions that would be emitted in August for different local power availability levels. Since GJU campus has no Energy Storage Systems (ESS), high local power availability levels are being guaranteed by the diesel generators which result in increasing CO_2 emission in winter where the PV production is low.

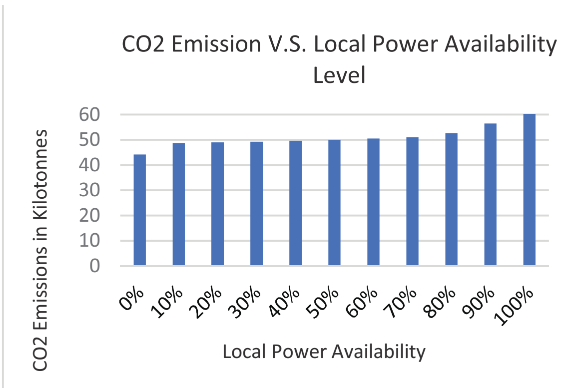

Fig. 5 Relation between CO2 Emission and Local Power Availability Level

As an assumption, the efficiency is considered to decrease with a percentage of 1% for every year of the PV system lifetime. An average value of 2.5% is assumed for every five years taking into consideration the degradation of the system efficiency. Table 14 shows the net CO2 savings of the PV System for every five years period of the PV system lifetime which is assumed to be 20 years. Data of 2015 was used to calculate the results and local power availability was set to 80%.

Table 2 CO_2 Savings which the PV system will result in

Period number	Total energy produced in MWh	Total CO2 savings in Kg
1	13689	6844500
2	13338	6669000
3	12987	6493500
4	12636	6318000

V. CONCLUSION

This paper investigated the environmental impact of smart MGs with renewable energies as main generation resource. The micro-grid is meant to provide an optimum scheduling of resources to meet power demand according to a pre-defined local power availability level. The needed power from diesel generators was economically dispatched on two diesel generators. The results show that using smart micro-grids with renewable energies as main generation resource would extremely help in reducing CO_2 footprint and hence help the world to be a better place to live in.

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