Behaviour of an Integrated EV Based on Renewable Energy Linked to the Distribution Grid: An Educational Tool

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Abstract. Electric Vehicles (EVs) are one of the renewable energy sources that can bring significant positive impacts to power system during their charging and discharging operations. According to this research an educational tool has been created to show students/users the Electric Vehicle’s behavior when integrated to the distribution grid. This research helps students/users to develop new algorithms for renewable energy and energy storage applications. A Matlab/Simulink module has been utilized to implement the integrated systems with simple, easy and flexible Graphical User Interface (GUI) for experimentation purposes. Furthermore, the developed educational tool aims to show that EVs can be efficiently charged by renewable energy sources connected to the grid with reduced charging costs. In addition, users can understand how those results can be sustainable for further studies and development. Unlike commercial wise tools, such a tool would add a promising methodology for the research methods and educational systems due to availability and user friendly approach.

1. Introduction
The global electricity supply sector accounts for the release to the atmosphere of over 7700 million tons of carbon dioxide annually [1]. So, increasing the efficiency of electric utilities and integrating modern and sustainable renewable energy resources to electrical grids will have the potential to decrease the carbon dioxide emissions to low levels. On the other side, transportations based on oil cause high amounts of carbon dioxide emissions too. Thus, technologies such as Electric Vehicles (EV) can bring significant improvements and solutions on both electric grids and transportation sectors [2, 3]. Clearly these new technologies require more research efforts in order to improve their sustainability with electric grids and roads infrastructure. Meanwhile, smart grids became the main title behind the modern construction of the modern systems integrating all renewable sources and communications [4]. Furthermore, Energy Management System (EMS) and Buildings Energy Management Systems (BEMS) are important parts of the new systems infrastructure.

As a matter of fact, Distributed Generation (DG), loads and storage units are forming the power grid. By controlling, monitoring and managing the grid’s operations, a smart power grid system is implemented. To achieve this, an extensive communication and networking infrastructure and system in deeded The interplay between the power networks and communication networks has been studied at several occasions [5-6] Due to these improvements and needs, educational tools must be found to help researchers, engineers and students about this topic and make them able to understand the complex...
technical issues. In this research an interactive educational tool has been utilized to implement the behavior of integrated EVs based on Renewable Energy Sources (RES) linked to the electrical distribution grid. An important approach of this research is to provide simple, easy and flexible GUI for experimentation purposes using Matlab/Simulink.

This paper is constructed as follows: Section one introduces the topic, section two explains the model configuration, section three illustrates a sample results and discussion results and section four concludes.

2. System Configuration

2.1. Distribution System (Microgrid)
The targeted system in this study is in the form of the latest designs of distribution systems which is micro-grid. In fact, due to deregulation implemented at many countries across the globe, micro-grids became the main target for electrical engineers to develop new projects and improve the performance of the distribution grid. Similarly, a 33kv, 50 Hz and about 10 MW load system includes all elements such as bus bars, transformers and renewable sources has been chosen in Matlab/Simulink environment for educational purpose as shown in Fig. 1.

In the figure, Diesel generator is the main source for the stable energy which is responsible about keeping the system reliable with its minimum generation cooperated with the storage systems. The storage system in the form of Electric Vehicles is integrated to the system based on special management system coordinating between the renewable and conventional resources. The GUI design will provide the users with enough parameters and structures to practice the management system for all the elements of the grid.

2.2. Renewable Energy
a) Wind farm:
The wind farm model is a model built using Simulink to represent simplified (DFIG) Doubly Fed Induction Generator based wind turbines to produce electrical power as a function of wind speed given as (1).
\[ P_w = \frac{\rho}{2} C_p (\gamma, \beta) A v_w^3 \]  

(1)

Where \( \rho = 1.229 \text{ kg/m}^3 \) is the air density, \( A \) is the area swept by the turbine blades, \( \gamma \) is the Tip-Speed-Ratio (TSR), \( \beta \) is the pitch angle.[7]

Equation (1) shows that wind energy variation is caused by wind speed fluctuations, as wind speed increases as the output power of the wind farm will increase and when it reaches its nominal speed, wind turbines will reflect the nominal output power of the wind farm.

The wind farm will shut down, only if wind speed increases above its maximum rated value and it will keep shut down until wind speed returns again to its nominal value or below it.

b) PV System

The PV system model is a model built using Simulink to represent a PV farm that produces electrical energy based on three factors: The area of the PV farm, Solar panels efficiency and the irradiance profile through the day. The relationship between these three factors and the output power of the PV farm is given as (2).

\[ P_{pv} = A E I \]  

(2)

Where \( A \) is the area of the PV farm, \( E \) is the solar panels efficiency per m2 and \( I \) is a variable represent the irradiance profile through the day per watt/ m2.

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2.3. Electric Vehicles

Electric vehicles models are models built using Simulink to represent random plugging profiles of electric vehicles with two behaviours as storage systems connected to the grid. The first behaviour is the charging behaviour where power flows from the grid towards EVs batteries and the second behaviour is the regulation behaviour where power flows from the EVs batteries towards the grid.

State of Charge (SOC) and the grid frequency are the main conditions that control the battery behaviour of every EV has been modelled. The state of charge (SOC) of EV (n) at instant (t) is given by \( n \leq 1 \), and the SOC dynamics are described by the simplified model as (3).

\[ X_{n,t} + 1 = X_{n,t} + \alpha_n \beta_n u_{n,t} \]  

(3)

Where \( X_{n,t} \), the State of Charge of EV (n) at instant (t), \( \alpha_n \) is the charging efficiency of EV (n), \( \beta_n \) is the battery capacity of EV (n) and \( u_{n,t} \) is the charging rate of EV (n) at instant (t).[8]

EVs batteries will remain only in the charging mode as long as their SOC is below 0.9, if their SOC exceeds 0.9 then the EVs batteries can operate on both charging and regulation modes.

The regulation mode operation of EVs batteries is controlled through PI controller. The PI controller controls the amount of power that can be flow from the EVs batteries towards the grid at a certain time. The rotor speed of the diesel generator has been taken as a feedback for the PI controller. When the rotor speed of the diesel generator decreases the diesel generator has to provide more power to the grid as a swing bus. The PI controller role is to detect the decrease of the rotor speed to provide an equivalent amount of power to the grid from EVs batteries until the rotor speed back again to a previously determined reference, as shown in Fig. 2.
3. **Graphical User Interface (GUI)**

The presented GUI was constructed as follows: six Inputs forms and four Output Graphs as shown in Fig. 3.

The input forms are as follows:

### 3.1 Diesel/grid parameters

Parameters shown in Fig. 4 were chosen to implement a similar Jordanian medium voltage distribution grid.

![Figure 2. Control diagram of the regulation mode of EVs](image)

**Figure 2.** Control diagram of the regulation mode of EVs

![Figure 3. Main GUI Configuration](image)

**Figure 3.** Main GUI Configuration

![Figure 4. Diesel/grid parameters](image)

**Figure 4.** Diesel/grid parameters
3.2 Wind farm parameters
Parameters shown in Fig. 5 are implementing a wind farm connected to the medium voltage distribution grid. The wind farm can be isolated from the system if the maximal wind speed is below the nominal wind speed. Parameters shown in Fig. 6 were chosen to implement a similar Jordanian medium voltage distribution grid.

| Parameter                  | Value |
|----------------------------|-------|
| Nominal Power (MW)         | 4.6   |
| Nominal wind speed (m/s)   | 14    |
| Maximal wind speed (m/s)   | 15.5  |

**Figure 5. Wind farm parameters**

3.3 PV farm Parameters

| Parameter                  | Value |
|----------------------------|-------|
| Nominal Power (MW)         | 7.9   |
| Efficiency (%)             | 11    |
| Shading caused by clouds (factor) | 0.9  |

**Figure 6. PV farm Parameters**

3.4 EV Parameters
Parameters shown in Fig. 7 are illustrating randomly distributed EVs connected to the low voltage distribution grid. The total rated power of EVs connected to the grid is 1.340 MW [9-10].

| Parameter                  | Value |
|----------------------------|-------|
| Rated power (kW) per EV    | 7.2   |
| Rated capacity (kWh) per EV| 30    |
| System efficiency (%)      | 90    |
| No of cars                 | 186   |

**Figure 7. EVs Parameters**

3.5 Residential Load Parameters
Parameters shown in Fig. 8 are representing the residential loads connected to the low voltage distribution grid.
On the other hand, output graphs are as follows: The first three graphs represent apparent, real and reactive power flow from the diesel generator towards the load, while the last graph represents load absorption from renewable energy resources as shown in fig. 3

4. Result And Discussion
The result is an example of using the GUI. However, an execution file can be created in a further step to simplify the process and to have a comprehensive coverage of the subject. According to Fig.9, the performance of the system in the presence of the electric vehicles is improving in the term of reducing the generation from the diesel unit. In this research, the integration of EVs considering their State of Charge (SOC) in addition to all charging and discharging configuration. Data have been taken following the commercially popular available cars in the Jordanian market [9-10].

In addition, the reduced amount of energy from the diesel unit is already stored in the EVs which results in increasing the sharing amount of energy produced by the renewable energy sources as shown in Fig.9

5. Conclusion
This study develops and describes an educational tool capable in a simple way to illustrate the utilization of storage systems in the form of electric vehicles in a medium size distribution grid. The
grid is somehow smart as the renewable energy and the two way communication configuration are important part of the system structure. The study guaranties an important educational platform for students and researchers in the area of micro grids and opens the door for a future improvement in the latest applications for energy related issues. Execution file will be created with the ability to develop an online wider GUI as a future work plan.

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