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Smart Grid Operation with Hybrid Renewable Resources and Hybrid Electric Vehicle

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Abstract - *The utilization of renewable energy resources will significantly increase to achieve clean and sustainable electricity generation. The management of the continuous growth share of variable renewable resources, integration of electric vehicles (EVs) and regulation of grid frequency require effective communication facilities of recent smart grids. In this respect, smart converters can provide efficient power conditioning devices to extract maximum power from renewable resources. In addition, the batteries of EVs could be used as distributed storage and discharge power back into the grid to compensate power deficit and fluctuation.*

Modeling and controlling of the hybrid resources within smart grid were carried out in this paper. The smart converter is switched to track the maximum power point MPPT of the solar panels. In addition, the pitch angle control and DFIG regulation are used to extract the maximum power under different wind speed and tidal stream velocities. The deployment of EVs can compensate power fluctuations and regulate the frequency deviations in the grid based on the proposed PID controller. In this paper, the integral minimization of time-weighted absolute error (ITAE) is used for on-line tuning of the PID controller parameters. Using Matlab/Simulink package, the smart grid is modeled and simulated using the weather data and then the grid performance is assessed under system disturbances and load excursions.

Key words-*Solar, Wind, Tidal Energy, Electric Vehicle, Smart Grid*

I.INTRODUCTION

Recently, there is an increasing interest in installing grid connected renewable resources such as wind, solar and tide [1-3]. This trend is attributed to economic and technical benefits of distributed generation DGs in smart grids [4]. On the other hand, DGs require efficient power conditioning converters to adjust their duty cycles to obtain stable MPP under different environmental conditions [1, 2]. It should be noted that wind and solar energy are not only intermittent but also are hardly predictable resources. On the other side, tidal current is intermittent but easily predictable and relies on the same technology of wind turbine. In this respect, the tidal current speed is lower than wind speed, while the water density is higher than air density [2,3].

The energy management of hybrid resources is a complex task. During low solar radiation

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conditions, photovoltaic (PV) panel cannot ensure the required solar generation. Similarly, wind turbine will not turn until the wind speed is equal to or greater than its cut-in value [2,3]. Therefore, the main objective of power management is to ensure efficient, stable system operation and to prevent energy deficit in grid loads. The real time communication in smart grid can facilitate the generation coordination and then enhance system performance [4].

The technical-environmental studies result in effective replacement of combustion engine-based cars with the electric vehicles (EVs) [5,6]. Through vehicle-to-grid (V2G) technology, the plug-in electric vehicles (PEVs) can be used as energy storage batteries (SB) and can discharge electrical energy back to smart grid. This means that PEVs can support the grid by regulating its voltage and frequency. This support relies on smart grid technology to enable effective utilization of variable renewable resources and electric vehicles [4-6].

The paper is organized as follows: the modeling of different renewable resources are discussed in Section II. On the other hand, Section III extensively reviews the interaction of the EVs with the smart grid. Moreover comprehensive case studies are performed using Matlab/Simulink to validate the proposed approach under real metrological data. Finally, the conclusions of the paper are drawn in Section IV.

II. MODELING OF HYBRID RENEWABLE RESOURCES

The configuration of proposed hybrid energy system is displayed in Fig. (1). It consists of offshore wind farm, photovoltaic (PV) panels, tidal current turbines, EVs (SB), and electric load.

Wind Turbine Modeling

Offshore wind energy will be a significant renewable energy source. The range of offshore wind speed variation is higher than onshore speed. Variable speed turbines using double-fed induction generator (DFIG) are used in recent wind farms [3, 6]. The available wind power Pw in blades swept area (A) is given by:

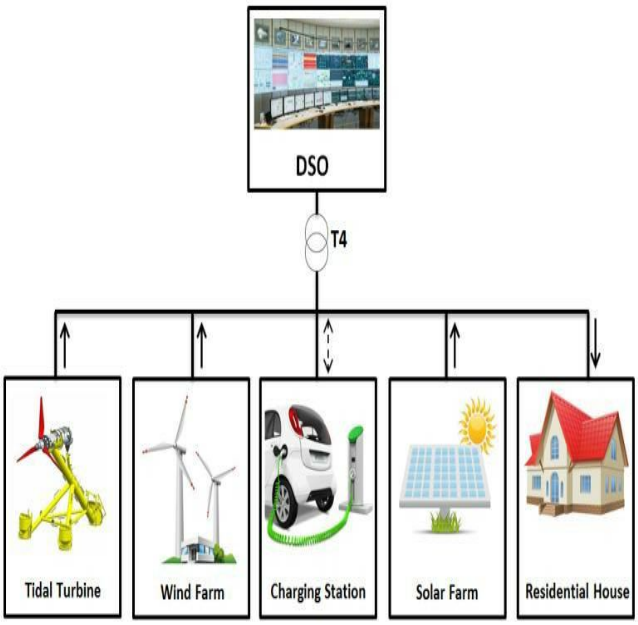

Fig.1: Hybrid Energy Resources Integration into Electric Grid with EVs

$$Pw = \frac{1}{2} \rho A (Vw)^3 \text{----------} \quad (1)$$

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Where, ρ is the density of air and V_w is the wind velocity m/s. The turbine can capture only a fraction of this wind power, which can be expressed as P_m, given by

$$Pm = \frac{1}{2}\rho A(Vw)^3 . C_p(\lambda,\beta) \quad \text{-------} \quad (2)$$

Where, C_p is the captured power coefficient. The maximum theoretical power extracted by an ideal wind turbine is limited to 59.26% of the power available in the wind [7]. The power coefficient $C_p(\lambda,\beta)$ of equation (2) is expressed as a function of tip speed ratio λ and pitch angle β. Any change in the rotor speed and/or wind speed results in a change in tip speed ratio leading to new operating point on the power curves for various speeds and pitch angles [3, 7]. For rated wind speed, the generating power equals the nominal power of the turbine. If the wind speed continues to increase the output power will be theoretically increased until the nominal turbine power. Further wind speed increase can damage the turbine. By turbine over speed protection, the turbine will shut down if the speed exceeds its maximum permissible value [13].

Grid connected PV Systems

Generally, PV cells are grouped together in similar modules which are interconnected either in series or parallel to form the final PV array. The current-voltage relation of PV array can be mathematically given by [8,9]:

The array output power is determined through multiplying equation (1) by array voltage and efficiency η. Equation (3) indicated that PV array exhibits a nonlinear relation of the I-V and P-V characteristics. From PV curve, there is a specific point at which the generated power is maximum. Therefore, a continuous adjustment of the array terminal voltage is required to extract maximum power (MPP) from the solar array.

The main components of the PV system consist of the solar array, DC/DC smart converter. In this paper, the generated voltage of the PV panel is adjusted to the suitable level corresponding to the maximum solar power using P&O method [1]. In P&O, the operating voltage of the studied PV array is perturbed by a small increment, and the resulting change of power, ΔP is used to update the array voltage as follows:

III. INTEGRATION OF EVS INTO SMART GRID

The majority of the EV charging systems take place at be undertaken at charging stations in public or working places [4]. However, the integration of the EVs can enhance grid performance, and improve power quality. The modern EVs are developed with a bidirectional grid interface and wireless communication to remotely allow power flow from or to the vehicle. Therefore, an intermediate aggregator has to be developed to coordinate the operation of the grid and vehicles [5]. The aggregator requires the default profiles of all used EVs. These profiles are forwarded by each driver to the aggregator through internet indicating vehicle location, the state of battery charge (SOC) and the availability of V2G implementation. Then corresponding commands are sent wirelessly to the vehicle

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for exchanging its electrical energy with the grid [4-6].

Plugged-in Electric Vehicle

The integration of EV can be considered as virtual distributed generation (VDG), where the plugged-in vehicles are clustered and controlled as distributed energy source [11]. Within this VDG concept, the distribution system operator (DSO) has a remote access to the EVs through the aggregator and the stored energy in the vehicle's batteries can participate in the energy supply.

The DSO and aggregator are connected over secure communication link. The DSO sends regulation commands to the aggregator to allocate the required regulation capacity from PEVs [6,11]. A schematic diagram of the EV system integration is displayed in Fig.(2). In addition, V2G controller is necessary to control the operation of the plugged-in EVs. In VDG operation, the frequency error will be the input variable to on-line tuned PID controller to balance the generation with load and to regulate the grid frequency. The SOC constraint of EV batteries has to be considered during grid regulation.

The PID controller parameters are on-line tuned by minimizing the integral of time weighted absolute error e in grid frequency (ITAE) given by [12]:

$$ITAE = \int t\,|e(t)|\,dt \quad \text{----------} \quad (3)$$

The procedure for on-line parameter tuning using smart grid facilities is summarized in the following steps:

- Initialize the controller parameter
- Simulate the grid behavior and save the time series of the output absolute error $|e(t)|$
- Minimize the ITAE using Matlab optimization function
- Update the controller parameters.

Storage Batteries Model

The surplus of the generated energy by hybrid resources is stored in EV's batteries, and supplies this energy back to load during the period of deficit generation taking into account the batteries SOC. The SOC of the battery depends on the previous SOC and the battery energy exchange either in charging or discharging mode during Δt between two time instants k, k-1. In all modes of operation, the SOC is subjected to the following constraint [14,15].

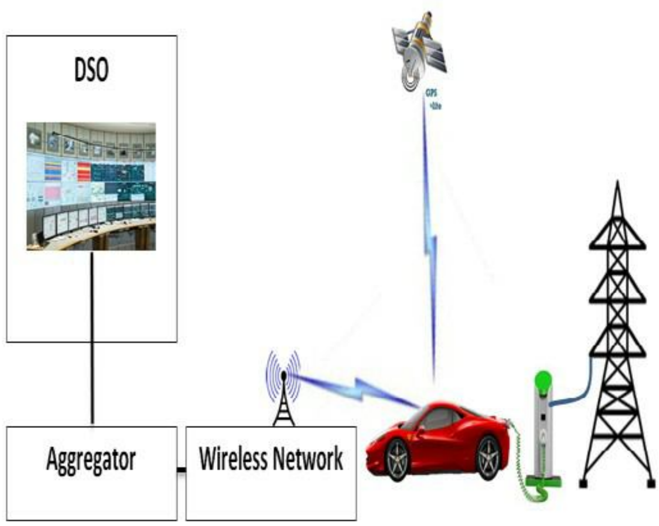

Fig.2: Configuration of Electric-vehide to Grid Integration

IV. CONCLUSIONS AND FUTURE RESEARCH

For efficient utilization of hybrid renewable resources, it is necessary to install smart converters to extract the maximum power of these resources. Matlab / Simulink models

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have been developed for offshore wind, solar and tide plants. The generated power from these resources was simulated using the actual recorded weather data in Kuwait. The simulation results indicated that the generated energy was tracking the maximum available power of the renewable resources.
In addition, this paper has presented the interaction of electric vehicles with the smart grid containing renewable energy sources. This interaction can provide ancillary services to the grid through frequency regulation by deployment of the described V2G concept. This can be achieved utilizing advanced communication and on-line control strategies of smart grids.

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