HYBRID WIND-TIDAL ENERGY SYSTEMS – LITERATURE REVIEW

MOHMED ASHGLAF[1], CRISTIAN NICHITA[1], JACQUES RAHARIJAONA[1]

[1] *University of Le Havre, Philippe Lebon 1123, 76063, Le Havre, France*

Abstract: One of the common drawbacks in Renewable Energy Sources RES is the power intermittency. In this paper an up to date literature review of hybrid wind-tidal power generation systems will be presented, focusing mainly on using different system configurations to manage and control power fluctuation in hybrid wind-tidal power generation. Furthermore, unit sizing selection; issues findings and challenges in design stages, advantages and critical problems of hybrid energy systems will be addressed.

Keywords: hybrid systems wind-tidal power systems; configuration; unit sizing; power fluctuation.

1. INTRODUCTION

Conventional energy sources have negative impact on the environment such as global warming due to CO2 emissions from fuel burning, nuclear hazards to human and environment, resources depletion, centralization of power units, cost and other reasons were behind the deployment and rapid development of renewable power resources.

On the other hand, natural power resources have some drawbacks, such as power instability and insufficiency, since it is straightforwardly depended on the climate, so as the climate changes produced power will be influenced by this change, that's why two or more of natural power resources need to be combined and managed. However, recently many researches have been conducted in the field of hybrid wind and tidal power generation systems including; feasibility studies, computer modeling, control strategies, and experimental work as well as associated energy storage devices in order to improve their performance and reliability.

As mentioned above, natural resources considered as unpredictable sources, means that, energy may be generated when it is not demanded and vice versa, so to overcome the problem of power intermittency, and thus improve the system performance, hybridization of two or more of renewable energy resources along with energy storage technology becomes an essential solution for power intermittency.

In general, the hybrid system operates in the following mode:
When generation more than load demands, generator supplies the load and charges the batteries in the same time. When load demand is greater than the generated power, tidal generator connected to make-up the power shortage in the system.

Energy storage system takes the role or partial participate when the load demand is higher than both sources. Tidal generator system has capacity factor of 30%–50% and that of wind generator is 25%–35%. If these two resources combined together renewable sources results in a system with overall good capacity. As system is located in offshore, therefore there is no danger of pollution from this hybrid system. Expected life time of such system is between 15–20 years [8] [9].

Due to the huge power available in oceans and seas, potential attention has been given to exploit and utilize Hybrid Wind-Tidal Power Generation Systems (HWTPGS). Therefore, large quantity of researches has been worked out to investigate the feasibility and reliability of hybrid wind tidal system.

Hybrid power generation system can be defined as when two or more of power generation systems sustainable or non-sustainable combined and controlled [1]. The hybrid wind tidal power generation system main composed of: energy sources, electronic power converters (AC/ DC and DC/AC), and storage devices as shown in the following figure.

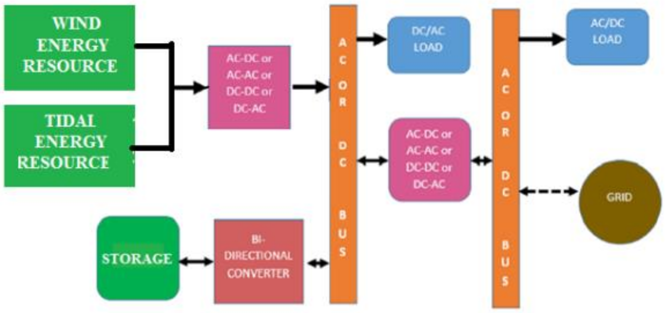

Fig. 9 Basic components of hybrid system [2]

The choice of systems to be combined depends up on multiple factors such as: feasibility study, site location, technical features, socio-cultural, and economic considerations [2].

Main renewable energy resources and storage devices are:

Tableau 1 Main renewable energy resources and storage

Main renewable energy sources	**Storage devices**
Wind	Batteries
Solar cell/ thermal	Super-capacitors/SMES
Tidal waves	Flywheel / Compressed air
Biomass	Pumped hydro
Geothermal	Thermal

Investigation and analyzing of hybrid power generation systems is a complex process. Therefore, many software packages are used to find out unit sizing, efficiency, reliability, and feasibility of hybrid power generation systems, these packages such as:

I. MATLAB/Simulink and PSCAD/EMTDC
II.HOMER: is used to simulate and size different model components energy sources and the hybrid alternative energy systems, based on the optimization of NPC.
III.HYBRID2: is used for the feasibility of hybrid alternative energy systems and performance.
IV.PVSOL: is used for both grid-on and grid-off connections performs analysis and cost estimation.
V.RAPSIM: is used for hybrid energy systems simulation PV, and DGs.
VI.TRANSYS: implemented for simulating solar PV, wind, solar thermal, and some other energy sources and lacks the optimization feature. [3] [4].

Many reviews have been conducted in renewable hybrid Power Generation Systems (HPGS) and the associated Energy Storage Systems (ESS), focused on system configurations, feasibility and reliability, as well as softwares and packages that used to simulate and evaluate such hybrid power systems, also challenges and alternatives based power generation been addressed [2] [5] [6] [7].

This paper organized as follows: Statistics on the current status and future trends of renewable power generation presented in section II. Configurations of hybrid energy system integration are discussed in Section III. Different hybrid wind-tidal power generation systems review in section V. Advantages and issues of hybrid energy systems are given in section IV. In section VI concludes the paper.

2. CURRENT STATISTICS AND FUTURE TRENDS OF RENEWABLE POWER GENERATION

In EEA report addressed the trends and projections of actual and approximated recent progresses in RES at the EU level and in the 28 EU Member States. [8]

The analysis shows that:
• The contribution of renewable energy by EU-28 increased in 2013 by 0.7 % to reach 15% compared with 2012.
•As calculated in August 2015 — EEA approximated estimates indicate that the EU RES share continued to grow in 2014 and reached 15.2 %.
•EU achieved its target in both 2013 and 2014, compared with the trajectories in the RED and the NREAPs.
A gross positive impact of RES on GHG emissions has been estimated by the current report. In 2014 demand on renewable energy increased, compared with the level of gross final RES consumption in 2005, this leads to:
•Reduce GHG emissions by 380 Mega-ton of CO2, equivalent to about 9 % of total EU GHG emissions;
•Fossil fuels consumption decreased by 114 Mtoe (million tons of oil equivalent), or roughly 10 % of total EU fossil fuel consumption;
•Primary energy consumption reduced by 32 Mtoe, which is equivalent to a 2 % reduction of primary energy consumption across the EU [8].

RE/AE has been growing rapidly comparing with other source of electricity generation around the world, according to IEO2016 Reference case, electrical generation expected to increases 69% from 2012-2040.

Figure (2) shows renewables are the fastest-growing source of energy for electricity generation; with average increases of 2.9% per year from 2012 to 2040 the global prospects of Long-term continue to improve power generation from renewable energy sources, natural gas, and nuclear power, in the IEO2016 Reference case, with much of the growth coming from wind power. After renewable energy sources, natural gas and nuclear power are the next fastest-growing sources of electricity generation. [8]

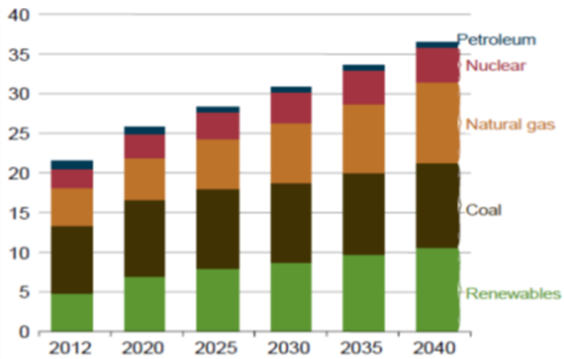

Fig. 10 World net electricity generation by energy source, 2012–40

According to EIA's analysis of the proposed CPP rule in (Figure 3), Solar energy is the world's fastest-growing form of renewable energy by an average of 8.3% per year, 859 billion kWh (15%), hydroelectric and wind each account for 1.9 trillion kWh (33%), for another renewables (mostly biomass and waste) for 856 billion kWh (14%) [9].

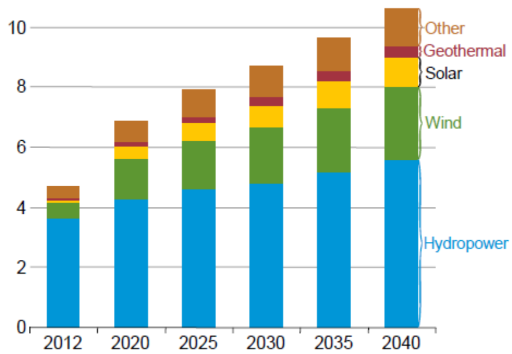

Fig. 11 World net electricity generation from renewable resources 2012-2040

3. CONFIGURATIONS OF HYBRID ENERGY SYSTEMS

Because of the intermittent nature of renewable energy resources, storage elements (SEs) are essential part to enable hybrid energy systems connected to power grid. SEs divided into two categories: “Capacity-Oriented” when long-term of energy storage and low response time are required for balancing power oscillation such as: Batteries, pumped hydroelectric systems, compressed air energy storage (CAES), and hydrogen storage.
“Access-oriented” energy storage systems, when short-time of storage energy and fast response are demanded such as: Flywheels, supercapacitors, and superconducting magnetic energy storage (SMES) are considered [10].
There are three possibilities for coupling hybrid renewable energy resources into power grid:
1) *OFF-grid stand-alone connection*: hybrid power resource connected to limited or isolated grid (micro-grid), such as island or farm in the country side.
2) *ON-grid connection*: hybrid power system is connected to open grid infinity or national electrical network.
3) *Hybrid connection*: renewable hybrid systems can be connected with both types of grids isolated or non-isolated grid [11].

A. Integration Schemes

Hybrid renewable resources can be integrated with power grids in many different ways, generally classified into three categories [12] :

DC-Coupled: - As shown in Fig. 1a in dc-coupled configuration, different distributed
1. generators DG and storage energy SE can be connected to a dc bus through power electronic (PE) converters. The dc sources and DC loads may be connected to the dc bus directly or through dc/dc converters, there are different types of DC–DC converters, but most commonly used are buck, boost and buck–boost converters to achieve appropriate dc voltage for the dc loads. AC loads or grid utility also can be connected to DC-bus through an inverter. Although, DC-bus configuration is simple in construction and no synchronization is needed, but it has its own drawbacks that, low efficiency, if DC/AC converter out of service AC loads cannot be supplied.

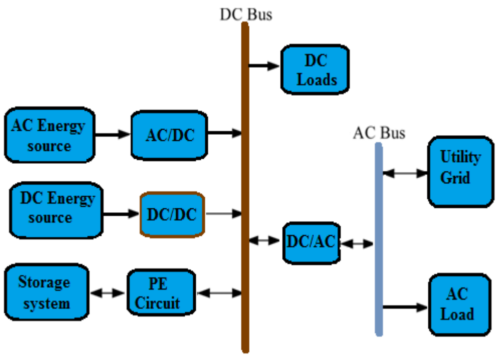

Figure 12 Schematic diagram of a dc-coupled hybrid energy system.

2. AC-Coupled: - As shown in fig. 2 AC bus can used for the integration of DG sources with ultimate AC outputs. DC sources need DC/AC converters (inverters) while those with AC outputs are connected to AC-buses either directly or through AC/AC converters (if required). DC-loads are connected to AC-buses by AC/DC converters (rectifiers) while AC loads are connected either directly or through AC/AC converters (if needed). There are two types of AC buses: (i) HFAC buses and (ii) PFAC buses.

High frequency (HF) AC Power generation systems and HF loads are connected to HFAC buses while those of Power frequency (PF) (i.e., 50–60 Hz) DG sources and PFAC loads are connected to PFAC buses. General hybridizations and energy flows of DG sources using HFAC Bus and PFAC Bus have been shown in Figs. 3(a) and 3(b), respectively. For obtaining DC power AC/DC rectification is needed, in case of both HFAC and PFAC configuration system. Utility grid can be connected to HFAC through PFAC bus (through a DC/AC or an AC/DC converter), to which AC loads can be connected.

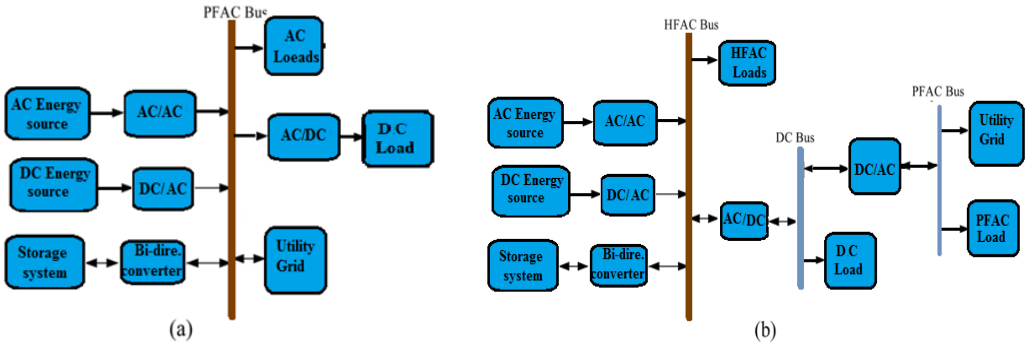

Fig. 13 Schematic of ac-coupled hybrid energy system: a- PFAC; b-HFAC

3. Hybrid-Coupled: - means that when AC and/or DC sources and loads connected together as shown below in fig. 4, such configuration has higher energy efficiency than the previous two type of configuration, but more complex to control.

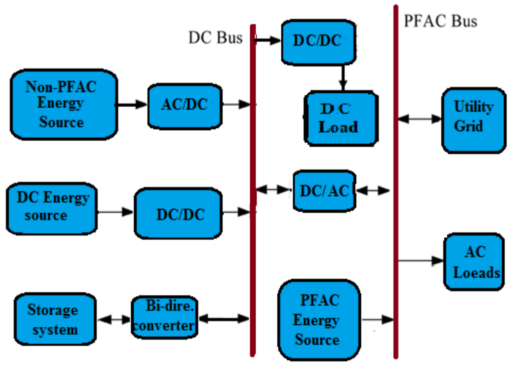

Fig. 14 Schematic diagram of a hybrid-coupled energy system

B. Unit-sizing and hybrid configuration selection

In the design stage of hybrid power generation system it is important to select and size the right configuration. Unit sizing and technology election can be straightforward or complex according to the system requirements and conditions e.g., geographic factors, desired system reliability, cost requirements there are many software packages executed to evaluate and estimate unit size and efficiency of hybrid renewable and non-renewable resources before real systems exist [7]. However, there are different technical methods used to figure out the best feet size and adequate configuration of the hybrid power system, many methods used for power system optimization such as linear programming (LP), interior- point-method (IPM) and heuristic methods such as DIRECT search algorithm, genetic algorithms and particle swarm optimization (PSO) can be used for component sizing and energy management of hybrid renewable power systems [13] [14]

In the beginning of designing stage, for a given hybrid power system hereafter very important questions must be answered to determine the general size and configuration of the given system

- What type of renewable energy system to be included?
- How many numbers of renewable energy units to be installed?
- How much the capacity of renewable energy units to be installed?
- Does a back-up unit, such as diesel generator, fuel cell etc. would be included in the system?
- Does energy storage would be integrated into the system?
- Is the system grid-off (stand-alone) or grid connected? [6].

4. HYBRID WIND-TIDAL POWER GENERATION SYSTEMS - REVIEW

a prototype experimentally designed of hybrid system consists of offshore wind turbine as main power unit with 6-pulse diode rectifier used to convert the AC generated into DC, and tidal turbine (one way clutch system) flywheel generator/motor based as complementary to guarantee the continuous supply availability to the grid power with IGBT bi-directional converter as shown in figure (7). The wind power has been subjected into short time fluctuation, tidal turbine used to overcome power fluctuation. The MPPT algorithm and PWM used to maintain the DC bus voltage at a level which gives maximum output power. The result shows that the tidal turbine is able to increase generation quickly in order to substitute power shortage in the power grid [15] [16].

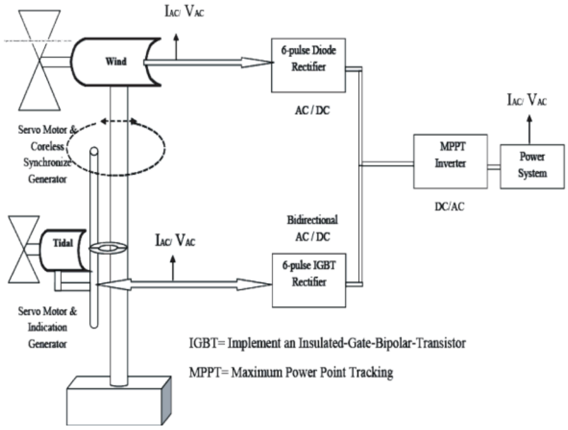

Fig. 15 Circuit configuration **[15]**

A hybrid Offshore Wind Farm (OWF) based (DFIG) and Tidal Farm (TF) based (PMG) connected to an onshore power grid using a flywheel energy storage system (FESS) see figure (8), the proposed system subjected to a wind-speed disturbance, the simulated result dynamic and steady-state characteristics were analyzed, and it can be concluded from that, FESS can be an effective solution for power stabilization in the power grid [17].

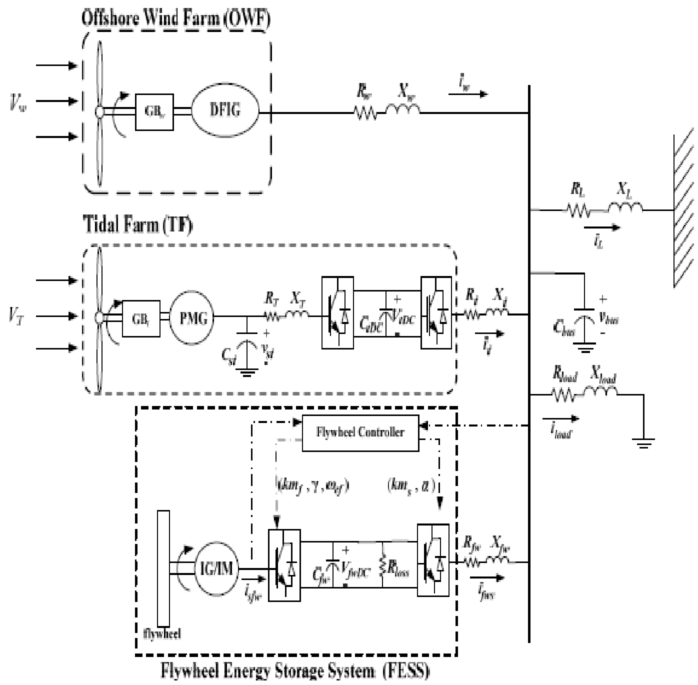

Fig. 16 Configuration of hybrid OWF and TF connected to a power grid using a FESS **[17]**

In this paper [18] control strategy used to smooth power output fluctuation of a hybrid system figure (9) comprises of wind turbines based doubly-fed induction generator (DFIG), Archimedes wave swing (AWS) based linear permanent magnet generator (LPMG) and tidal turbine based DFIG (flywheel) as generator/motor system is used to smooth short time output power fluctuation. The tidal speed considered as set point of this control strategy, if the tidal speed is less than the cut-in speed tidal turbine disconnected mechanically and the DFIG operates as electrical motor by the bi-directional converter. The proposed system numerically simulated in MATLAB, the obtained result was satisfied to reduce the power fluctuation in the power system.

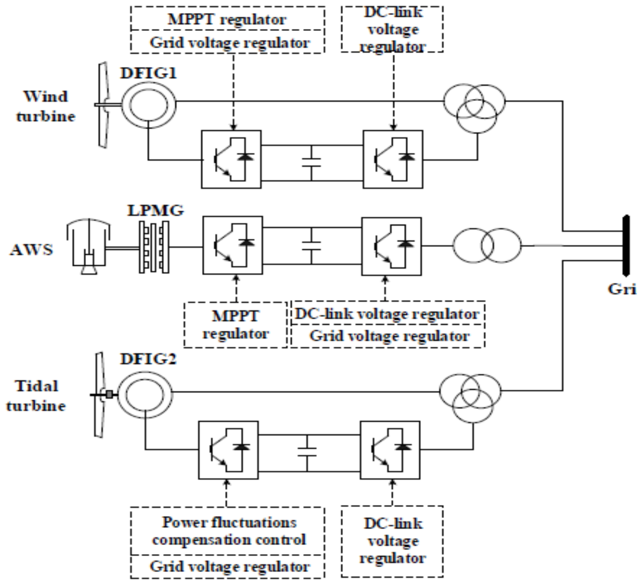

Fig. 17 Schematic configuration of the HORCES [18]

Authors suggested in this study dynamic modeling, simulation, control and energy management in an isolated integrated power generation system consisting of (offshore wind turbine, tidal turbine, micro-turbine and battery storage). Feasibility of this system and optimal sizing is obtained based on genetic algorithms (GA) micro-turbine with a battery is suggested to be as back-up to the system, least square algorithm is implemented to estimate a model-power consumption of the micro-turbine. Adaptive feedback and space vector control is used to track the maximum power point in the wind speed, pitch angle zero, yaw system is not considered, supervisory controller is used to manage the power produced by the system and consumed by the load. Simulation and dynamic modeling are fulfilled using MATLAB Simulink^{TM}7.2 this system shows that it can be used in the isolated rural and mountainous areas where are far from the power generation network. [19] Different electrical configurations of hybrid wind-tidal power system connected to DC-bus simulated in MATLAB, wind turbine based a (PMSM) and tidal turbine based a (DFIG) as shown in figure (10). Two control strategies MPPT, PI Controller and oriented-field control used to extract the maximum power possible in the wind, from the obtained results it can be concluded that more stability and easy to control the power variation [20] [21].

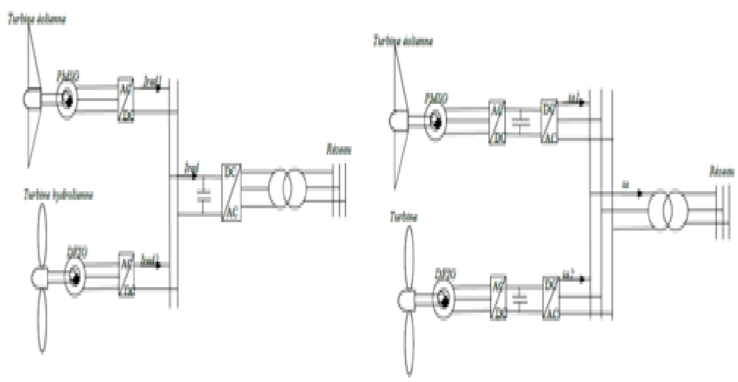

Fig. 18 different configurations of hybrid power system connected to DC-bus [20] [21]

As shown in fig. 11 hybrid wind-tidal system connected to the individual bridge rectifier. The rectified output connected to PWM (Pulse Width Modulation) inverter through common DC link along with PI controller. Finally the inverter connected to the required grid system which controls the voltage and power factor of the system. The wind and tidal energy conversion system has been simulated in MATLAB/SIMULINK. Final result shows that, this combination of wind/tidal turbine can be an alternative for future power resource**.**

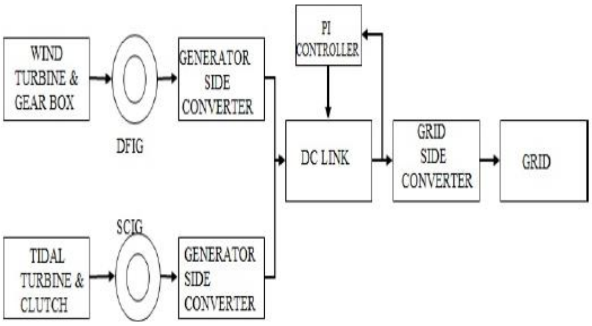

Fig. 19 Block diagram of proposed system [22]

This research is devoted to propose new method to stabilize the output power of hybrid wind-tidal system by using Modulated Power Filter Compensator (MPFC) connected to the network , the proposed MPFC is controlled through a tri-loop dynamic error driven PI controller the simulation results indicate a significant improvement to the power quality [23]. Dynamic model of offshore wind and tidal turbine system based different types of generators namely (DFIG, SCIG and DDPMSG) has been carried out to analyze system stability. All models are validated using a common property of the generator for the validation. The obtained results indicate that system stability has directly proportional relationship with the resistance, while inversely proportional relationship with the inductance [24].

In this study, dynamic model of hybrid offshore wind and tidal energy system based gearless (PMSG) simulated in MATLAB/Simulink®. MPPT and controlled rectifier via PWM both used to control the generator speed as shown in the figure below. The results prove that, the independent controlled rectifier is sufficient to adjust the rotation speed of the generator consequently, extracts the maximum power of both turbines and improves system stability [25].

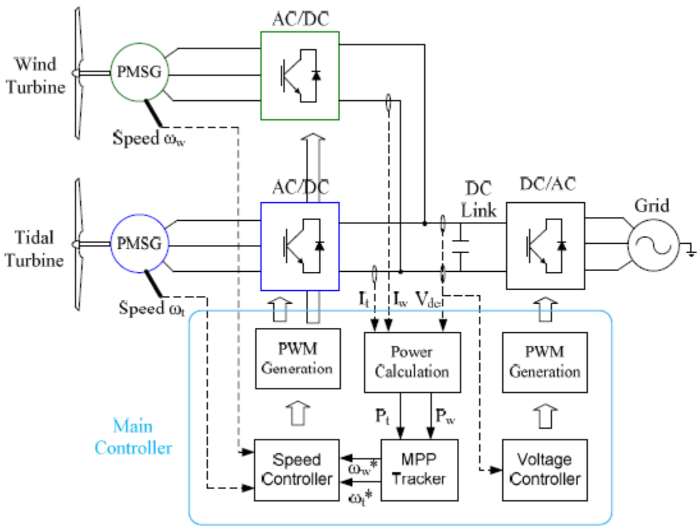

Fig. 20 hybrid wind/tidal turbine based PMSG [25]

In this paper [26] authors proposed four tidal turbine and one wind turbine combined together and connected to DC line, the proposed system modeled and simulated in PSCAD/EMTDC from the obtained results the control system maintained the DC voltage constant.

As shown in the figur 13 below hybrid wind-tidal power system and hydraulic accumulator as energy storage system are modeled and simulated in MATLAB. PID controller (standard torque controls) used to regulate hydraulic distribution between auxiliary pumps. Using such system demonstrates very high efficiency in terms of system stability and maximum power extraction [27].

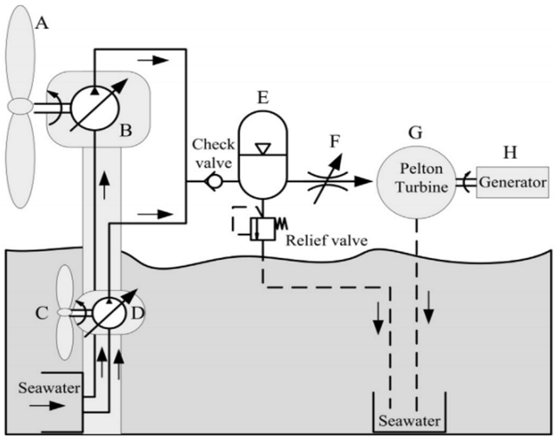

Fig. 21 Schematic of hybrid wind-tidal turbine system [27]

Individual channel analysis and design (ICAD) – a frequency domain-oriented framework for multiple-input multiple-output (MIMO) are used to analysis dynamic behavior of PMSG-based hybrid wind-tidal system, as well as the internal coupling evaluation and multivariable structure functions (MSFs) is achieved, the suggested system simulated and assessed in MATLAB/Simulink. The obtained results of the control system based victor control strategy, focused on the generator-side converter shows that it is not necessary decoupling loops in order to have sufficient control system design and performance [28].

The significant contribution of this work [29] is to reduce power fluctuation in the power grid due to the variation of wind speed and the slow response of the tidal turbine to fast change, this problem can be eliminated by integrating a small-scale battery energy storage system (BESS) as shown in figure (14).

Tidal turbine is connected to DC side via IGBT bi-directional converter, whereas offshore-wind turbine is connected to DC side via diode rectifier, the proposed system simulated in PSCAD/EMTDC. Integration of BESS was successful accomplished and effective compensation achieved in the hybrid offshore wind tidal generation system HOTT.

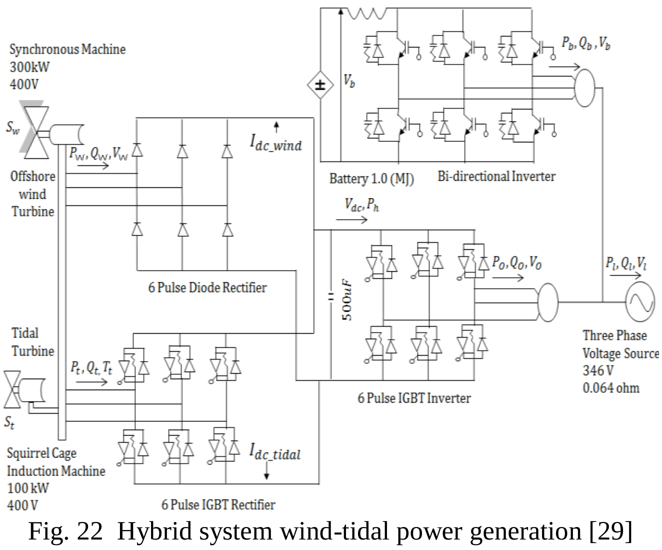

Fig. 22 Hybrid system wind-tidal power generation [29]

The main objective of this study [30] is to investigate the feasibility and reliability of hybrid wind-tidal generation system with battery ESS, through analyzing its dynamic behavior and generated power using mathematical modeling approach. The suggested system under study supposed to be connected to isolated grid. The obtained results show that, the system efficiency depends on the rotor diameter and wind/tidal speed. Authors in this paper [31] discuss the design and optimal cost analysis of a hybrid wind and tidal power generation system equipped with battery ESS. The optimal design is performed with the HOMER (Hybrid Optimization Model for Electric Renewable) software. According to the results it is economically feasible as off-grid power connection. This paper [32] addressed the integration of wave energy into a conventional offshore wind farm. More specifically, to understand the effects of the co-location on both energies Depending on the following methodology: i) the location and wave climate, ii) The co-located farms design, iii) the wave propagation model. The obtained results indicate what is called "shadow effect" yields to produce an area of lower wave height inside the offshore wind farm to increase the weather windows for O&M of the wind turbines. A model of isolated hybrid offshore wind- diesel- tidal turbine based DFIG and DDMPMSG generators is discussed in [33] FACT device and STATCOM controller used to manage the system reactive power of the system as well as GA and PSO, as result stability improvement and efficiency achieved in the prosed system. A standalone hybrid wind-diesel-tidal turbine based fuzzy and Unit Power Flow Controller UPFC are used to control the reactive power of the suggested systems [34] the proposed fuzzy controller shows better results in settling time and overshoot in the system.

Authors present in this paper [35] both steady state and dynamic performance analysis of hybrid wind/marine-current farm turbine based induction generator and superconducting magnetic storage unit (SMES), control method of a frequency-domain approach based on a linearized system model using Eigen techniques and a time-domain to control power flow, reactive and active power delivered to power grid. It can be concluded from the simulated results and under various conditions of wind and tidal speeds that PID controller has an effective power control improvement and achieved more stabilization in the system. A hybrid system composed of diesel-based generator, wind/PV/ battery used to supply isolated network presented in [36] concentrated study given to the dynamic performance and effects of renewable energy sources on system stability and power generation quality a simulation program called the RPM-Sim (Renewable-energy Power-system Modular Simulation) is implemented to investigate the case under study. An improvement noted in the system stability and quality. In this study case of unit sizing [37] hybrid of wind, photovoltaic, tidal and battery as an auxiliary source simulated in MATLAB software. The main objective of this configuration is to minimize the annual cost of 20 years of operation. The Equivalent Loss Factor (ELF) has been used as an index to evaluate the system reliability level. Particle Swarm Optimization (PSO) is used for optimal sizing the system. Results shown that it has minimum cost and satisfy all constrains.

5. ADVANTAGES AND DISADVANTAGES OF HYBRID ENERGY SYSTEMS

Advantages of Hybrid Systems

1. Some of power units can be installed very close to the end user without high risk issues, such as PV panels.
2. Reduce power cost.
3. Endless resources.
4. It is possible to be installed as a part of industrial process to exploit their wastes and used for power generation.
5. Reduce GHG emission.
6. Safe to environment.

Disadvantages of Hybrid Systems

Despite their significant benefits to the environment and great long-term potential for sustainable energy development, hybrid RE/AE systems have some disadvantages which make barriers to employ this source of energy.

1. Not all resources available in everywhere, i.e. (in the north sun resources not available as in the south while wind resources available more in the north).
2. More complex to be controlled.
3. Generated unstable power according to the resources situation.
4. A storage system is essential for overcoming the problem of power fluctuation in the grid.

5. Sometimes one power unit is not sufficient to provide the required power so hybrid system is needed.
6. It is not easy to be integrated with the general electrical network.

6. CONCLUSION

The conclusion of this review can be summarized in the following points:

1. Most of the researches executed in software simulation only
2. Most of the studies addressed off-grid configuration system
3. The main drawbacks of the hybrid wind tidal system is the power intermittency
4. Energy storage system play essential role for damping power fluctuation energy management.
5. The development of power electronics (power converters) increases the ability of control power generation system and hence the system efficiency.
6. Different software packages used for hybrid system simulation in order to analyze steady state and dynamic performance unit sizing, as well as investigate the feasibility, efficiency and control robustness.

Because of the rapidly increasing population and depleting of conventional sources with their economic and environmental concerns, they are considered unsuitable for addressing the issues of escalated energy demand and environmental damages. As an option, alternative energy (AE) sources are considered as the potential sources coupled with the fact that they are durable /continuous, non-polluting, and monetarily cheap or available in free. The unpredictable nature of these alternative energy sources is their common drawback and considered as inability to harness usable power for some considerable duration of time over the year.

In this paper a comprehensive review on hybrid wind tidal configuration, focusing on power generation stability, system configurations and unit sizing selection, important issues and challenges in design stage are addressed; energy management and storage are discussed. Advantages and critical problems of hybrid energy systems presented.

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