Hybrid Hydro Renewable Energy Storage Model

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Abstract. This paper aims at presenting wind & tidal turbine pumped-storage solutions for improving the energy efficiency and economic sustainability of renewable energy systems. Indicated a viable option to solve problems of energy production, as well as in the integration of intermittent renewable energies, providing system flexibility due to energy load’s fluctuation, as long as the storage of energy from intermittent sources. Sea water storage energy is one of the best and most efficient options in terms of renewable resources as an integrated solution allowing the improvement of the energy system elasticity and the global system efficiency.

1. Introduction
Sea water storage hydropower systems utilize elevation changes to store off-peak electricity for later use. Water is pumped from a lower reservoir through wind turbine & tidal turbine to a reservoir at a higher elevation during off-peak periods. Subsequently, water is allowed to flow back down to the lower reservoir, generating electricity in a method similar to a conventional hydropower plant. A seawater storage energy power station is identical to a regular pumped-storage system. The main difference consists of the lower reservoir, which is the sea presenting an unlimited volume of water and storage (Dam). A storage facility is needed, in order to store the excess of energy produced. Under this project, sea water storage presented itself as a good option to overcome the storage problem. Hence the integration of renewable energies in the system needs to be compensated by a storage solution that will help to solve the problem of demand and supply. The supply always needs to be guaranteed, and with the intermittent characteristic of renewable sources.

2. Methodologies
The concept used in sea water storage arrangements is moderately not complex. Water in a reservoir (Dam) of a given height has potential energy. When the water flows down either through a stream, it has a velocity due to gravitational force and this flowing water has kinetic energy. This kinetic energy can then be harvested and converted into electricity by the use of a turbine generator.
**Figure 1.** Overall diagram for sea water storage energy modeling. HG: Hydro Generator, WG: Wine Generator, TG: Tidal Generator, S: Sensor, PC: Pump control, LI: Level indicator, PO: Power output control.

The height between where the water starts to flow and the turbine is known as the head height. At times of the high speed of wind or sea water current speed is high when the cost of electricity is low, pumps or pump turbines can be used to pump water into the Dam (upper reservoir) for later use. Besides just relying on off-peak electricity to fill the upper reservoir, excess energy generated by irregular renewable energy sources (wind & tidal) turbine can be used, thus making the facility act as storage for unused electricity [1]. Overall system shown in Figure 1.

A flow of sea water or wind speed with a given velocity passes through the turbine blades, which then turn the turbine that generates electricity [2]. That electricity feed to the pump for transfer sea water from low reservoir to high reservoir. Let’s definite at the turbines output efficiency base on water level of the upper reservoir with integrated systems.

2.1. Turbines productivity

**Tidal turbine:** Various turbine designs have varying efficiencies and therefore varying power output. If the efficiency of the turbine $\eta$ is known the equation below can be used to determine the power output of a turbine [3] [4]. The energy available from these kinetic systems can be expressed as: $P_t = \frac{\epsilon \rho A v^2}{2}$

Where: $P_t =$ the power generated (in watts), $\epsilon =$ the turbine efficiency, $\rho =$ the density of the water (seawater is 1025 kg/m³), $A =$ the sweep area of the turbine (in m²), $V =$ the velocity of the flow. Relative to an open turbine in free stream, depending on the geometry of the shroud shrouded turbines are capable of as much as 3 to 4 times the power of the same turbine rotor in open flow.

**Wind turbine:** Let us consider total available wind power at wind speed $v$, passing through the cross-sectional area $\rho$, the power generated by a wind turbine is known by following expression: $P_w = \frac{\eta \rho \nu^3}{2}$

Where $\eta$ is the overall efficiency of the system and $\nu =$ the radius of the turbine [5].

2.2. Procedure of the system

To determine the number of wind turbine ($N_{\text{wind}}$), the number of tidal turbine ($N_{\text{tidal}}$), and the required dam water volume $V_{\text{water}}$ is expressed as follows. The time limit $t = t_0; t_1; \ldots ; t_T$. Average powers $P_{\text{wind}}(t)$ and $P_{\text{tidal}}(t)$ respectively generated by WT and TT, and average power demanded by the load $P_d(t)$, at every moment $t$ in the time period $[t_0; t_T]$. The total power generate from outlet dam: $P_d(t) \leq N_{\text{wind}} P_{\text{wind}}(t) + N_{\text{tidal}} P_{\text{tidal}}(t)$. The optimum water volume requires producing electricity from the generator: $P_{\text{water}}(t) = N_{\text{wind}} P_{\text{wind}}(t) + N_{\text{tidal}} P_{\text{tidal}}(t) - P_d(t)$
Figure 2. Optimal water volume indicator.

The optimal water volume of the dam determined by Obtainable Water Volume (OWV), shown in figure: 2. The available energy storage in the dam at the moment \( t \): \( OWV(t) = OWV(t_0) + \sum_{t=t_0}^{t} P_{W-MIN}(t) \) Where \( t = t_0, t_1, \ldots, t_N \). So total power generates from tidal turbine and wind turbine: \( P_U(t) = N_{wind} \frac{\pi \eta \rho q^2 g h(t)}{2} + N_{Tidal} \frac{\epsilon_{PAV}}{2} \)

To calculate the theoretical power available from falling water, equation was used: \( P = \eta \times \rho \times q \times g \times h \) Where \( P \) is power (W), \( \eta \) is turbine efficiency (%), \( \rho \) is density (kg/m\(^3\)), \( q \) is water flow rate (m\(^3\)/s), \( g \) is acceleration due to gravity (m/s\(^2\)) and \( h \) is head height (m). As for the pump turbines to be used in the sites, the turbine theoretical output tool can be used to consider the control structure of pump turbines that is appropriate for the given sites [6] [7]. The number of turbines can be manipulated by having multiple penstocks connected to the mouth of the reservoir. In order to analyze the sea water storage energy system scenarios, daily based time setup transient control models for water flow were developed. Figure 3 shows the control diagram of the sea water transient model. The model works on a twofold level: water volume and energy parameter. At the water side, the water storage Dam will be account the water volume (\( W_{water} \)) and water pressure in order to define the actual water level (\( W_{water} \)).

Figure 3. over all control diagram. (R1: RTU1, R2: RTU2, V: voltage, I: Current, P: Power, HG=Hydro Generator).

The control logic of the energy production is aimed at maintaining a daily autonomy water level in the Dam in case of power plant default, by indicating the power need to activate the power feedback unit PFU by \( (P_{\tau, \text{PFU}}) \), shown in figure 4. To this end the storage capacity request will vary in depends on
outsourcing water from outside. The energy control level defines the sources needed to supply the requested power to the PFU units ($P_{req}$) by giving priority to the renewable source ($P_{ren}$) in situations when wind and tidal turbine are in running mode. The initial water storage condition is settled to Obtainable Water Volume state as, whatever value is variable according to condition of the wind-tidal turbine [8].

2.3. Control configuration

The comprehensive hardware connection of the deliberate hybrid system containing two induction generators one is wind turbine (WG) and another is tidal turbine (TG). Power synchronize unit can combine two different forms of renewable energy together. The both power source will apply to the pump for store water (Energy) to the upper reservoir. The variable excitation capacitors C1 and C2 are respectively the self-excited capacitors of WG and TG and they can be effectively switched through the use of the controller of the PLC under various wind-tide speed and different loading conditions of the feeding pump. The fuses may serve as over-current and cut-off protective devices in case of faults while the contactors may execute parallel operation and isolation under dissimilar commands of the PLC. The digital power meters are installed for accessing the measured electrical data of the renewable energy power generating systems. The projected PLC also connects to a remote PC through site network. Hereafter, the proposed real-time monitoring and control system can use the load supervision arrangement to perform different functions such as wind-flow or tide-flow, data measurement and collection, pump status, real-time load monitoring and load-shedding control. The human-machine interface developed by software can collect, manage, and visualize both wind-flow or tide-flow data and information needed of the hybrid wind-tide system.

A Programmable logic controller is employed to control the Dam water level through wind-tidal turbine electricity powered pump system and two remote terminal units are employed to collect the data from sensors. A Delta made PLC is chosen in the implementation. Due to the limitation of the number of Analog inputs and the capability to read the sensors, the data acquisition system used to control the wind-tidal-hydro turbine system. The RTUs are developed based on two microcontroller system by developing such microcontroller system, various sensor modules could be acquired easily. One microcontroller is used to obtain the environment data from solar ultrasonic sensor, integrated water level, wind speed sensor, wind direction sensor, and water current sensor. These sensors, except the wind speed sensor, are connected to the microcontroller via the Analog input. While the wind and sea water current, voltage and power sensor is connected via the digital input. All systems have their protection, control systems and power analyzer. Communication path starts at the data source device (generators, sensor, and power analyzer), it follows to a specific transducer (RS-232, RS-485 or others to TCP/IP), it continues to the network switch and finally to a PC. That configuration creates a network where only circulates relevant data circulates, but it also allows remote supervision. Each renewable energy source has different treatment for condition monitoring and fault diagnosis [9]. The system works with two kinds of models. First, mathematical models are used when the equations that represent equipment performance are known. That includes the speed of the wind module or the speed of the tide current; second, heuristic models are considered when only input-output signals are available and there is not enough information available about inside turbines behavior to build a mathematical model. After the implementation of each model, the following activities will carry out: simulation and calculation of standard deviations, model fitting, definition and refinement of fault analysis.
Figure 4. Flowchart for water-power control.

The control stagey decides on which situation last (nth) particular hydro pump will be switched ON or OFF and when a particular renewable energy source is to be connected or disconnected depending upon the water level of the Dam. Figure 5 show a flow chart, which reflect the logic information of all renewable energy source and water level condition of the dam. When wind-tidal turbine total power generation becomes less then set point power ($P_{set}$), automatically switch off the last (nth) hydro pump. If ‘no’ then the total produce power by renewable energy sources is greater than set point power, for that condition last (nth) hydro pump will be enable (on state) and meet the demand for water level. On the other side when water level is high-high than all hydro pump must be off state.

Figure 5. Flowchart for Wind-tidal turbine running condition.

3. Conclusions
The present work presented a special storage system—the hybrid hydro energy storage system—which has proven to be a possible and a good energy option as described in the two case studies (i.e. based on renewable energy efficiency and sea-water control solutions). Renewable hydro-storage represents a technology of storing energy during periods of low demand. This technology is viable, since it uses electricity in low demand hours to pump water from sea and use it in hours of high demand. One of the goals was to verify and compare characteristic parameters that will lead to a successful
implementation of such system. It was concluded that these systems present several positive characteristics, namely to store energy, to generate profit, to provide flexibility regarding start-ups and shut-downs and to compensate the energy load fluctuations. One of the major outcomes is the possibility to provide the storage of energy from intermittent sources (e.g. wind and tidal) making the whole system more flexible and reliable, with a better performance, and improving the elasticity and water-energy nexus most valorized. This project demonstrates how the profit can be maximized, being a strong alternative to fossil fuels. Studies regarding renewable energy penetration, investments, employment, decrease in imports and fuel costs and the reduction of CO₂ emission helped to prove this system viability.

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