Scheduling of Wind-Pumped Storage Hydro Power Plants

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Abstract: Wind energy is variable renewable energy source. To utilize this variable energy source in an electricity grid system, it is desirable to regulate this efficiently and store the excess wind energy when not required and delivers when needed. The pumped storage is a proven energy storage system which can be efficiently deployed in conjunction with variable wind energy source to match the power demand profile.

In this study it has been attempted to use wind energy supported with pumped storage. In the pumped storage, two reservoirs at different elevations are used, where water is pumped from lower reservoir to upper reservoir at the time of excess wind energy and during the time of high demand water is released from upper reservoir to lower reservoir to hydro power energy. Pumped storage plant is added to electricity system to achieve high economic gain from wind energy system having variable and intermittent characteristics. Such exercise is only possible if forecasting of wind energy is available. It has been shown that profits are achieved with wind-hydro system instead of only wind system with grid.

Index Terms—Wind energy, Pumped storage plant, Hydro power energy

1. Introduction

Power is very important tool in overall development of any nation in the world. It is the tool to build the economic growth of the country. There has been an ever-increasing need for more and more power generation recently in all countries of the world.

Today, primarily fossil fuels are used to heat and power the homes and fuel the cars. It’s convenient to use coal, oil, and natural gas for meeting the energy needs, but a limited supply of these fuels on the earth is available. We’re using them much more rapidly than they are being created. Even if we had an unrestricted supply of fossil fuels, using renewable energy [1] is better for the environment. We often call renewable energy technologies “sanitary” or “green” because they produce few if any pollutants. Burning fossil fuels, still, sends gases into the atmosphere, trapping the sun’s heat and contributing to global warming. The dilute nature of renewable energy sources make them capital intensive however integrated system can take advantage of inherent variety among the different manifestations of renewable energy system and satisfy the rural energy requirements as and when it occurs in the form required. Table 1.1 gives the renewable energy potential and achievement in India.

Table 1.1 Renewable Energy Potential and Achievement Status in India [2]

<table>
<thead>
<tr>
<th>Source/Technologies</th>
<th>Unit</th>
<th>Potential</th>
<th>Achievement 31.07.2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>MW</td>
<td>45,195</td>
<td>23864.91</td>
</tr>
<tr>
<td>Small Hydro (Up to 25 MW)</td>
<td>MW</td>
<td>15,000</td>
<td>4130.55</td>
</tr>
<tr>
<td>Bio-power</td>
<td>MW</td>
<td>16,881</td>
<td>4418.55</td>
</tr>
<tr>
<td>Solar Power</td>
<td>MW/ km²</td>
<td>50</td>
<td>4101.68</td>
</tr>
<tr>
<td>Waste to Energy</td>
<td>MW</td>
<td>2,700</td>
<td>91</td>
</tr>
</tbody>
</table>

The Wind power program in India was initiated towards the end of the Sixth Plan, in 1983-84. A market-oriented plan was adopted from inception, which has led to the successful commercial development of the technology. The broad based National program comprises wind resource assessment activities; research and growth support; application of demonstration projects to create awareness and opening up of new sites; development of infrastructure ability and capacity for manufacture, installation, operation and maintenance of wind electric generators; and policy support.

Table 1.2: Gross potential/ present installed capacity in different states [3]

<table>
<thead>
<tr>
<th>State</th>
<th>Installed Capacity (MW) 31.07.2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tamil Nadu</td>
<td>7455.2</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>4450.8</td>
</tr>
</tbody>
</table>
A site must have minimum average annual wind power density 200W/m² at 50m above ground level. There is a vast network of 618 wind monitoring stations in country [4].

1.1 Current tools for storing wind energy

The current technologies which are currently being used or developed to store wind were as follows:
1) Compressed Air Energy Storage
2) Flywheel
3) Batteries
4) Pumped-Storage Hydroelectricity as Wind Storage

1.2 Pumped-storage hydroelectricity as wind storage [8] [9]

This energy storage process also known as hydroelectric storage is for translating large quantities of electrical energy to potential energy by pumping water to a higher elevation, where it can be deposited and then released to pass through hydraulic turbines and generate electrical energy. An indirect procedure is needed because electrical energy cannot be stored effectively in large quantities. Storage is necessary, as the feeding of electricity is highly variable between day and night, between weekday and weekend, along with among seasons. Consequently, much of the generating equipment needed to meet the greatest daytime load is idle or lightly loaded at night or on weekends. During those times the excess capability can be used to generate energy for driving, hence the necessity for storage.

A typical pumped-storage development is composed of two reservoirs of basically equal volume situated to maximize the difference in their levels.

1) Upper Reservoir: A conventional dam is built to create a reservoir. The water in this reservoir flows through the hydro power plant to generate electricity.

2) Lower Reservoir: Water exiting the power plant flows into a lower reservoir rather than go back into the river and flowing downstream.

These reservoirs are connected by a system of watercourses along which a pumping generating station is located. Under favourable geological conditions, the station will be located underground; otherwise it will be situated on the lower reservoir. The principal equipment of the station is the pumping-generating unit. The machinery is reversible and is used for both pumping and generating, it is deliberate to task as a motor and pump in one direction of rotation and as a turbine and generator in opposite rotation. Using reversible machinery, the plant can pump water back to the upper reservoir. This is done in off-peak hours. The second reservoir fill-ups the upper reservoir by pumping water back to the upper reservoir; the plant has water to generate electricity during periods of highest consumption.

1.2.1 Efficiency of Pumped Storage Plant

A pumped storage scheme suffers from disadvantage as conversion of energy taking place two times and in calculating the overall efficiency if the plant, the losses occurring in each unit of the plant must be taken into account for the separate operations of pumping and generating. Next are the figures for deriving approximately overall efficiency of conversion.

The maximum overall efficiency of 67.5% derived above may be considered as an average figure. The overall efficiency value may fall if the plant has to work frequently below their full load output. The annual average value may go even to 64%. And these values do not include the double transmission loss which is important if pumped storage scheme is remote from the source of electrical energy and from load to be supplied. [7]
Table 1.3 Overall efficiency of Pumped storage plant

<table>
<thead>
<tr>
<th></th>
<th>Efficiency of unit, in percent</th>
<th>Overall efficiency of conversion in percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer</td>
<td>98</td>
<td>98</td>
</tr>
<tr>
<td>Motor</td>
<td>88</td>
<td>94</td>
</tr>
<tr>
<td>Pump(Turbine)</td>
<td>88</td>
<td>83</td>
</tr>
<tr>
<td>Pipeline</td>
<td>98</td>
<td>81</td>
</tr>
<tr>
<td><strong>Generating</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipeline</td>
<td>98</td>
<td>78</td>
</tr>
<tr>
<td>Turbine</td>
<td>92</td>
<td>72</td>
</tr>
<tr>
<td>Generator</td>
<td>96</td>
<td>69</td>
</tr>
<tr>
<td>Transformer</td>
<td>98</td>
<td>67.5</td>
</tr>
<tr>
<td><strong>Overall efficiency</strong></td>
<td></td>
<td>67.5</td>
</tr>
</tbody>
</table>

1.2.2 Scheduling of pumped storage plant [5]

Power plants which supply electrical power to grid near to be operated according to the demand of power in the grid, PSP breed for power plants operates only when there peaking variations in the demand. The limits of these peaking variation needed to be addressed as many factors and restraints are concerned in doing this. These factors and constraints are nothing but volume of water available, time ratio of pumping to generation, efficient of PSP operation[6], etc.. To address these limitations for the operations of Hydro Electric units in plant is nothing but Scheduling of PSP.

2. Basic Concepts Of Wind-Pump Storage Hydro Power Plants And Scheduling

Wind pump storage hydro power plants are nothing but storing wind energy in the form of hydro energy by using pumped storage power plants. As wind energy is not consistent through the time, it should be stored when it is available more than the demand. Demand goes high when the wind energy is can’t supply the whole power that is required, and then the shortage power is taken from pumped storage plant which was stored during off peak hours.

The above figure shows the layout of wind-pumped storage plant in which wind energy is used to drive the pumps of the PSP [10] during pumping mode. In the above figure it is shown that the pump and hydro generator separate, but now a day’s both pumping and generation is performed by reversible turbine only this means that there will be no separate components for pumping and generation.

In general, a PHPS system operates by using the extra power generation at times of low electrical demand to pump water to a reservoir at a higher elevation. When there is an advanced demand for power, water is released back into the lower reservoir through a hydraulic turbine which generate electricity which can be run through the grid to satisfy the peaks during high load demand. A typical PHPS system consists of an upper and lower reservoir, connecting lines, pump turbine, and motor-generator set. A facility can be brought available within 90 seconds and can be functioning at full power within 120 seconds (Khartchenko, 1998)[14]. A pumped-storage facility can shift from pumping to generation or from generation to pumping in 180-240 seconds, giving PHPS among the fastest charge and discharge rates and the capability to keep up with near real time fluctuations in wind speed (Khartchenko, 1998)[14]. Wind power is not consistent throughout, it keep on changing with respect to time. In order to trap the excess wind energy when available there should be a system in such a way that it can be brought to available with in a small period of time. As pumped storage plant has the ability to come online within a short period of time it can be integrated with wind farm for better power output.

2.1 Benefits of combining with wind generation[11][13]

Why is a PHPS system preferable to any of the other storage solutions available? Wind, as it
continues to grow towards 20% capacity, requires a system that can operate on a utility scale. As an intermittent energy source, wind needs a storage component that can charge and discharge within minutes if not seconds to keep in time with real time power fluctuations. As a renewable energy source, wind should be partnered with a storage system that is fresh, inexpensive, renewable, and domestically abundant. A PHPS system can answer all of these concerns and it is a well-developed technology which can be confidently implemented.

As the power output of a wind farm is proportional to the cube of its wind speed; therefore, a sustained drop in wind speed means a considerable drop in power output. If a sudden drop in wind speed occurs, the reduced power generation will be experienced within minutes requiring wind to be partnered with a storage system that can come online quickly. A PHPS system’s has an ability to come online within 90 seconds and be fully functional within 2 minutes. This is one of the fastest ramp-up times among energy storage devices. With the ability to quickly come online, a PHPS system allows a base load plant, typically coal, natural gas fired or nuclear, to continue to operate at base load levels while taking the place of “peaked” plants that use inefficient and often costly fossil fuels to ramp up quickly.

The clean and renewable nature of a PHPS system cannot be discounted. Water is a domestic, renewable, and naturally occurring fuel, and a PHPS system does not directly produce carbon dioxide releases. It cannot be denied that emissions are released during the construction of a PHPS system; however, its operations are emissions free over a potential lifetime of 50-100 years.

3. Swot analysis for a wind pumped storage system

3.1 strengths

1. It can provide secure water level, if needed.
2. At many areas in India there is a high average wind speed. This gives more power from a wind turbine.
3. No CO₂ emission is from a wind turbine.
4. A wind turbine is a symbol for renewable energy production today and has a Positive global image.
5. There is persistent wind in many places in India.
6. The power comes from renewable energy source.

3.2 Weaknesses

1. There is little knowledge or experiment in this field.
2. It is inevitable to expect an extra implementation cost.
3. Not a profitable project to install a wind pumped storage system, for electricity production from the extra water, at hydro power plant in India.

3.3 Opportunities

1. The average electricity price in India is high. Building a wind pumped storage system for power production from the pumped water will most likely be profitable. It will depend on local condition like average wind speed and head of the water.
2. Wind power is not always usable because of the consistency on the wind. No wind, no power! But with a wind pump and a hydropower plant, hydro turbines produce the energy but the wind turbine and the pumps provide the water.
3. Many countries are now focusing on green technology energy production

3.4 Threats

1. Strong and irregular winds may cause damage to wind turbine.
2. Energy Policies and unstable political atmosphere

4. Scheduling

Scheduling is the process of deciding how to commit resources between a varieties of possible tasks

4.1 Decomposition of hydropower scheduling

Hydropower scheduling problem is decomposed in following three sections as shown in figure 3.2. Discussed below

![Figure 3.2: Scheduling problem decomposition](image-url)
4.1.1 Long-term Scheduling [12]

The longer-term scheduling models supply boundary conditions for models with shorter time limit. An important crossing point principle between the models is the marginal cost of water (water value). The long-term scheduling replicas are typically stochastic models for calculating an optimal strategy for hydro system operation. For the power manufacturers, a long-term model may either be used for scheduling own resources in a market environment, or to do value estimation. In the latter case, the complete system must be modelled; the long-term models have to use aggregated reservoir models and do not deliver boundary conditions for the short term models with sufficient accuracy.

4.1.2 Medium-term Scheduling

The medium term model may be seen as a link between the long and the short term scheduling models, a means of converting results from the long term scheduling process to a form suitable for giving correct urges to the short term scheduling process. The medium term model has a planning horizon of typically one year, and the same time raise (one week) and system model as the long term model. However, the medium-term models should have an imprecise similar topology description in the optimization procedure as the short-term model to be able to supply appropriate boundary conditions.

4.1.3 Short term scheduling

The short term scheduling is solved as a deterministic problematic, with a sufficient time increments to support a more detailed system model than in the previous models. Coupling to the intermediate term model is based on an incremental water value description for the individual reservoirs. The objective of short-term scheduling is to minimize the cost for covering a load obligation or maximizing income if a market is present. This optimization must be achieved while implementing the strategy from the long-term planning. The result is optimum generation schedules for the generation assets in the system. The challenge is in either case to find the strict balance between proficiency of the hydropower plants and the resource cost including the optimal unit commitment sequence.

5. Conclusion

In this work, an approach was developed to find out the optimum operation strategy of hydro generation/ driving for a small scale hydro system has been taken. The water storage ability allows enhanced profits for wind energy connection. During peak hours, the available wind energy is complemented with hydro generation. During off peak hours a part of wind energy is used to store energy by pumping water. Optimum results of short term (hourly) operational strategy for a combined wind turbine and hydro generation pumping equipments is presented.

6. Future scope of work

It is recommended that following works may be done in future
1. A small capacity wind energy system is measured in this work, this approach can also be attempted to very large wind-hydro storage facility.
2. In this work the levels of the reservoir were taken in terms of energy, in further study levels of reservoirs may be taken in terms volume of water in reservoir to get the release limits of the pumps and turbines.
3. Scheduling for short term interval (say 15 min.) can also be done, as the dispatch is presently done in such short intervals
4. The same study can also be done to a remote system by knowing the load demand.
5. Unit commitment of wind as well as pumped storage plants is also recommended for further study.

7. References

[7] Chen P.H., “Pumped-Storage Scheduling Using Evolutionary Particle Swarm Optimization” IEEE


