# ECONOMIC ASSESSMENT OF INSTALLING PUMPED STORAGE HYDROELECTRIC POWER PLANT IN EGYPT

By

**Diaa Abdellatif Abdelaziz Ghazala**

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

in
ELECTRICAL POWER AND MACHINES ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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**Title of Thesis :**

**"Economic Assessment of Installing Pumped Storage Hydroelectric Power Plant in Egypt"**

**Key Words :**

Pumped Storage – Electricity generation – levelized cost of electricity – traditional power plants – Fossil Fuel)

**Summary :**

This thesis studied all the economic aspects relating to constructing Pumped Storage Hydroelectric Power Plant (PSHPP) in Egypt to be compared with traditional generation technologies based on levelized cost of electricity (LCOE) to conduct the conditions at which PSHPP has a competitiveness over traditional generation technologies. This thesis studied how interconnecting PSHPP to the Egyptian Unified Grid has an impact on the fuel costs in the grid. The avoided fuel amounts based on opportunity cost concept resulting from utilizing PSHPP instead of fossil fuel power plants were also studied.

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Diaa

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# NOMENCLATURE

| | | |
|---|---|---|
| A.F | : | Availability factor |
| BOOT | : | Build own operate transfer |
| BTU | : | British thermal unit |
| CAES | : | Compressed air energy storage |
| CBE | : | Central bank of Egypt |
| CCGT | : | Combined cycle gas turbine |
| CPI | : | Consumer price index |
| CSP | : | Concentrated solar power |
| D | : | Debt/loan |
| DC | : | Direct current |
| DCF | : | Discounted cash flow |
| D.F | : | Discount factor |
| DLC | : | Daily load curve |
| DR | : | Discount rate |
| E | : | Equity |
| EES | : | Electrical energy storage |
| EEHC | : | Egyptian electricity holding company |
| EETC | : | Egyptian electricity transmission company |
| EGEAS | : | Electrical generation expansion analysis software |
| EPRI | : | Electrical power research institute |
| $E_p$ | : | Annual energy needed to pump up water |
| ES | : | Energy storage |
| $E_t$ | : | PSHPP electricity generation in the year *t* |
| F.O | : | Forced outage rate |
| GBP | : | Great Britain Pound |
| GHG | : | Greenhouse gases |
| GW | : | Giga Watt |
| GWh | : | Giga Watt hour |
| H.C | : | Heat content/heating value of a fossil fuel type |
| $H_d$ | : | Expected operating hours per day |
| HFO | : | Heavy Fuel Oil |
| HPPEA | : | Hydro power plants executive authority |
| H.R | : | Heat rate of traditional technology |
| Hy | : | Hydro |
| IDC | : | Interest during construction |
| $I_t$ | : | Investment cost at a certain year t |
| Kg | : | Kilograms |
| Km | : | Kilo meter |
| KV | : | Kilo Volt |
| kW | : | Kilo Watt |
| kWh | : | Kilo Watt hour |
| LCOE | : | Levelized cost of electricity |
| L.E. | : | Egyptian Pounds |
| LFO | : | Light Fuel Oil |
| Li-ion | : | Lithium ion |
| Lit | : | Littre |
| MBTU | : | Million British thermal unit |
| Mnth | : | Month |

| | | |
|---|---|---|
| $M_t$ | : | Operation and maintenance costs in the year *t* |
| MVA | : | Mega Volt Ampere |
| MW | : | Mega Watt |
| MWh | : | Mega Watt hour |
| m | : | Meter |
| mm | : | Millimeter |
| $m^3$ | : | Cubic meter |
| N | : | Number of years |
| NaS | : | Sodium sulfur |
| $N_d$ | : | Number of days of scheduled maintenance |
| NG | : | Natural Gas |
| NPW | : | Net present worth |
| n | : | The expected lifetime |
| OCGT | : | Open cycle gas turbine |
| OEM | : | Original equipment manufacturer |
| O&M | : | Operation and maintenance |
| P | : | Output power capacity |
| PSHPP | : | Pumped storage hydroelectric power plant |
| Pt | : | Egyptian piasters |
| $P_t$ | : | Pumping costs in the year *t* |
| PV | : | Photo Voltaic |
| $P_w$ | : | Price of 1 cubic meter of water |
| $R_d$ | : | Cost of debt as a percentage |
| $R_e$ | : | Cost of equity as a percentage |
| SMES | : | Super magnetic energy storage |
| St | : | Steam |
| $T_c$ | : | Corporate tax rate |
| UPS | : | Uninterruptable power supply |
| $UR_c$ | : | Upper reservoir water capacity |
| US/USA | : | United States of America |
| WACC | : | Weighted average cost of capital |
| $W_l$ | : | Annual loss of water due to evaporation |
| Yr | : | Year |
| $\eta$ | : | Cycle efficiency of PSHPP |
| $ | : | United States dollars |
| ₵ | : | United States Cents |

# ABSTRACT

Energy sustainability is the main concern of the world especially because of the limited natural resources while the demand on these resources is rapidly increasing. This situation directed the governments to look for other energy alternatives to sustain their energy resources. One of the clean energy sources is pumped storage hydroelectric power plants (PSHPPs) which is one of the most applicable energy storage technologies on a large scale capacity generation and on the level of economic viability. Although PSHPP is not a recent electricity generation technology, it has some limitations to construct such as the site suitability and the huge investment costs needed compared to traditional generation technologies from fossil fuel. Therefore this thesis studies all the economic aspects relating to constructing PSHPP in Egypt, specifically on Attaqa Mountain as one of the suitable places in Egypt to construct such kind of generation power plants according to previous studies, to be compared with traditional generation technologies based on levelized cost of electricity (LCOE) concept taking into account different scenarios for PSHPP (including operation and capital costs) and different scenarios for fuel prices of traditional technologies to conduct the conditions at which PSHPP will have a competitiveness over traditional generation technologies. PSHPP as a clean energy source is expected to have an impact on the amounts of fuel consumed in the Egyptian Unified Grid, so this is another concern of the thesis to study how interconnecting PSHPP to the Egyptian Unified Grid have an impact on the fuel consumed in the grid using a software package tool called Electrical Generation Expansion Analysis Software (EGEAS) that is used for system operation optimization to calculate if there will be any avoided fuel costs in the Egyptian Unified Grid in case of interconnecting PSHPP or no. Another economic concept which is the opportunity cost represented in the amounts of fuel saving resulting from utilizing PSHPP instead of fossil fuel power plants that are expected to generate the same energy of PSHPP.

# CHAPTER 1
# INTRODUCTION

## 1.1 Introduction

Electrical Energy Storage (EES) technologies can be used to store fluctuating electricity generated from renewables during the low electricity demand time periods and submit this stored energy back during higher electricity demand periods. For example, wind turbine often generates more electricity at night when the wind availability is high but the electricity demand is low and to get the maximum value of wind energy; EES can be used to displace this electricity generated from wind by storing it in one of EES technologies to be released at the time periods of higher electricity demand.
EES technologies are variant according to the method of storage, the amount of stored energy, and for how long and how quickly this stored energy can be released. EES technologies can be used in different applications such as power quality applications by applying short bursts of electricity and other technologies are suitable for storing and restoring back large amounts of electricity over long time periods.
Wind and solar energy are inconstant or variable electricity sources. Wind energy only produces electricity when the wind is available, and solar energy only produces electricity when the sunlight is existing, therefore the output of these sources varies with the speed of wind and light intensity. Since the electrical grid operators' role is to match the supply of electricity with demand constantly, this makes the intermittent renewable energy sources more challenging to integrate with the electrical grid than traditional electricity generating technologies (e.g., nuclear, coal and natural gas), which can be controlled to produce energy with specific amounts at specific periods. The electrical grid operators have various options for controlling the fluctuation of electricity supply coming from renewable energy sources, one of which is EES.
EES technologies can be classified into different categories according to their suitable storage durations, response times, functions, or the form of energy they store as in Figure 1.1.[1]

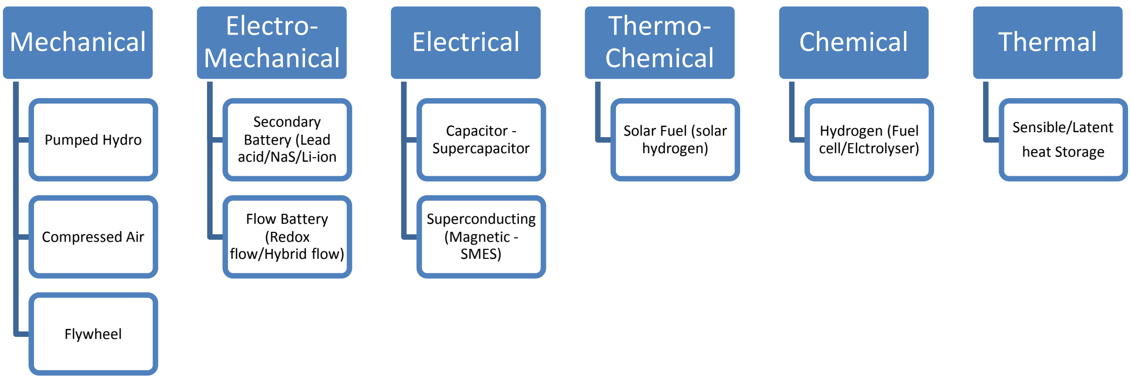


Figure 1.1: Classification of EES technologies by the form of stored energy

One of EES technologies is pumped hydro storage plant. The basic concept of pumped storage hydro power plant (PSHPP) involves pumping water from a lower reservoir for