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Combined Gravity and Compressed Air Energy Storage System

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Abstract: ***The electrical power system should always have adequate power to fulfill the consumer requirements. Currently, we are using conventional sources of energy such as coal, natural gases for this purpose. But it is predicted that the conventional sources of energy will be completely depleted in the next 50 years. Hence the world is making a rapid transition towards non-conventional /renewable sources of energy such as solar energy, wind energy. But the only problem with renewable sources of energy is that they are not constant throughout every part of the day. Hence we need some promising energy storage systems so that they can store energy during the availability of renewable energy and will be utilized when renewable energy is not available. In this paper, we are introducing the new technology for energy storage, i.e. "Combined Gravity and Compressed Air Energy Storage System" which can increase the system's reliability and can help to achieve more stringent emission reduction targets on the path towards decarbonization.***

Keywords: Gravity, Compressed Air, Energy Storage, Power System, System Reliability.

I. INTRODUCTION

Energy storage systems are becoming a very important aspect of electric power systems due to the increasing use of renewable sources of energy. The first thing which comes into the picture whenever we talk about power storage is the battery. but in the grid level applications of batteries, various disadvantages are present such as high initial cost, high maintenance, low life, hazardous effect on the environment. Due to these drawbacks of the batteries, we cannot use batteries for grid-level energy storage. Hence there is a need to find some better and more effective alternative to batteries for energy storage.

At the beginning of the 1890s, The first known use of pumped hydro storage was found in Italy and Switzerland. This system was used to store the energy in the form of the potential energy of water with the use of gravity. This system was very effective in energy storage at specific locations with the availability of required water reservoirs and heads. but this system is highly location specific and requires a tremendous quantity of water for its operation hence this cannot be implemented anywhere according to our system needs.

As per Wood Mackenzie's latest report, as shown in figure 1, it is clear that the global energy storage capacity will be growing at a compound annual growth rate (CAGR) of 31%, recording 741 gigawatt-hours (GWh) of cumulative capacity by 2030. Hence there is a need for new energy storage systems, which will be able to store huge energy with high efficiency and fewer losses. This has created interest in developing new forms of gravity energy storage, to capture the benefits of pumped hydropower without its land-use requirements.

A new gravity energy storage technology using suspended weights and compressed air for energy storage has been proposed in this paper .This system offers several advantages, including minimal land-use. This storage technology is expected to be most desirable for obsolete deep mine shafts, but the maximum energy storage capacity of this system is limited by the dimensions of the shaft and weight which can be practically used. This motivates us to investigate the potential opportunity for energy storage.

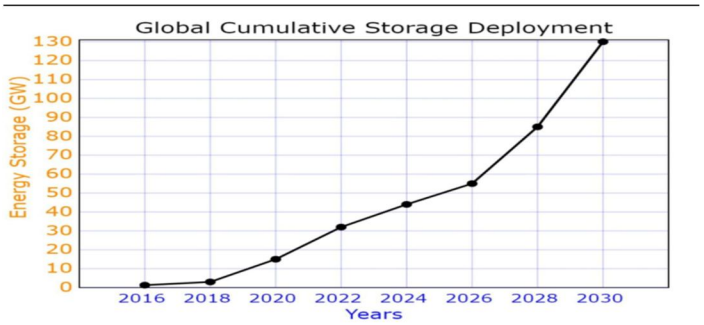

Figure 1 : Increase in Global Cumulative Energy Storage

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II. METHODOLOGY

The block diagram as shown in figure 2 consists of various components which makes-up the combined gravity and compressed air energy storage system. The energy is stored in the proposed system with the help of the motor, gearbox, and winches additionally the energy is also stored in the system with the help of the motor followed by the compressor as shown in figure 2. The stored energy can be injected back into the grid whenever it is required with the help of generators.

1) Whenever the maximum demand on the grid is low, the extra energy available on the grid is stored in the proposed system.
2) The energy can be stored in our system by converting the grid's electrical energy into mechanical energy with the help of the motor and applying this mechanical energy to uplift the weight by passing through the gearbox.
3) Additionally, this system can also store energy in the form of compressed air by compressing the air through the compressor.
4) During the time of peak demand on the grid, the energy stored in the proposed system can be injected back into the grid by following two methods
a) By lowering the weight and applying the generated mechanical energy to the generator via the gearbox for the formation of electrical energy.
b) By heating the compressed air in the reheater and expanding it in the turbine. so the turbine will produce the mechanical energy which can be applied to generators for the production of electrical energy.

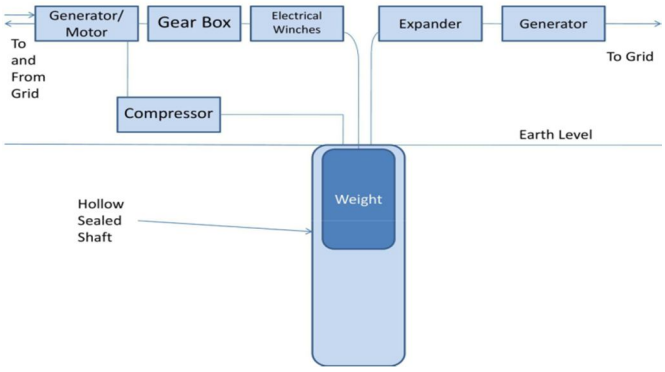

Figure2: Block Diagram of Proposed System

Various Blocks of the above block diagram are explained as follows:-

A. Generator /Motor

Generator / Motor block is used to interact the energy storage system with the live grid. At the time of energy storage into the proposed system this block acts as the motor and stores the grid's energy into the energy storage system. on the other hand, whenever the energy is to be transferred from the storage system to the grid, this block acts as a generator and injects the power into the grid.

B. Gear Box

The Gear Box block is generally made up of mechanical gears. This block is used to increase or decrease the speed in such a way that generator output can be varied according to the requirements. The gearbox also plays a very important role in keeping the grid-induced power frequency in the tolerance band.

C. Winches

The pair of winches is the mechanical device that is used to pull in or let out the suspended weight in the vertical shaft. Electrical Winches are also called the mini electric hoist. Winches are divided into various types but the most widely used winches are air winches due to their high versatility, durability, and safety.

D. Weight & Shaft

The weight is made up of the steel bars and is suspended in the sealed earth shaft. The power of the system depends on the weight and the capacity of the proposed system depends on the depth of the shaft.

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E. Compressor

The air compressor is a pneumatic device that converts power into potential energy stored in the form of pressurized air. The air compressor is a specific type of gas compressor. The compressor is operated by the motor. it is used to compress the air into the sealed shaft at the pressure of 7 bars.

F. Expander

The Expander block consists of a combustor and the turbine. Whenever there is need to generate electrical power, the compressed air in the sealed shaft is passed to the expander. In expander this compressed air is heated in the combustor and is expanded in the air turbine. This air turbine generates the mechanical power which can be further converted into electrical power with the help of the generator.

III. MODELING

Our main objective is high power system reliability, high energy storage system efficiency, long life and fast speed of response. Figure 3shows the simulation model of the proposed system.

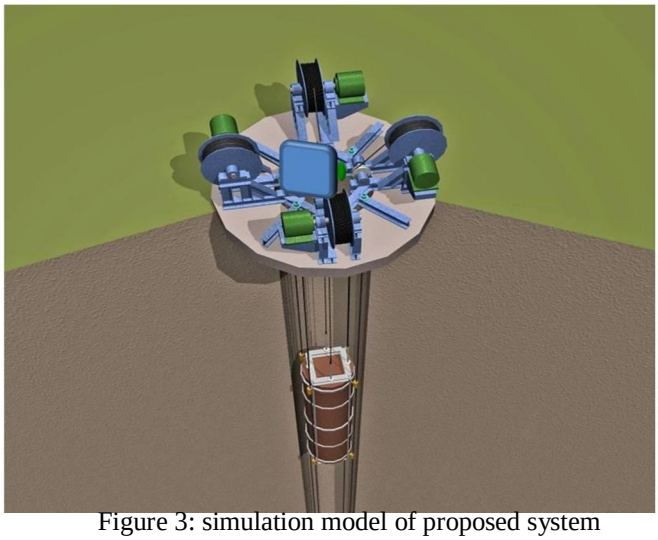

Figure 3: simulation model of proposed system

IV. ANALYSIS AND RESULT

A. Sample Calculations

For finding the performance of the system we are assuming the system with shaft depth of 200 meters and weight of dimensions 5x2 meters suspended into it as shown in Figure 3.

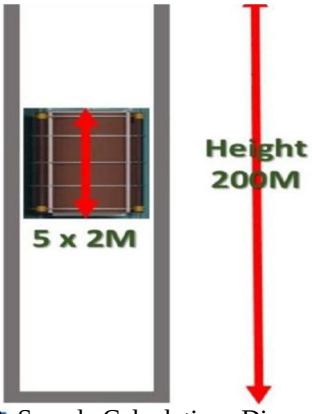

Figure 3: Sample Calculations Dimensions

This system stores energy by the suspended weight as well as by compressed air. so, we will find the energy stored by both the methods one by one.

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1) Energy Stored By Suspended Weight

Considering,

H = Shaft height (Depth) in meters, h = Height of Weight, r2 = Radius of the weight, m = Mass of weight, g = Acceleration due to gravity.

Now,

Volume of suspended weight = π x r2 x h = π x 1 x 5 = 15.7 m^3

Mass of Suspended weight = Volume x Density = 15.7 x 7850 = 123 Tonn

Potential Energy Stored by this weight = m x g x H = 123 x 10^3 x 9.8 x 200

Volume of suspended weight = π x r2 x h = π x 1 x 5 = 15.7 m^3

Mass of Suspended weight = Volume x Density = 15.7 x 7850 = 123 Tonns

Potential Energy Stored by this weight = m x g x H = 123 x 10^3 x 9.8 x 200 = 241080000 J

Converting from Joule to KWH, energy stored by the weight in our sample system will be 67 KWH.

2) Energy Stored By Compressed Air

Our system is compressing the air at the pressure of 7 Bar. For Compressing the air at the pressure of 7 Bar, the compressor 16.5 KW of power is consumed and from which we get 2.83 m^3/min of compressed air.

Now, The volume of shaft is given by

Volume of Shaft = π x Radius of shaft x Effective shaft height

Volume of Shaft = x 1 x 195 = 612 m^3

So, the stored energy by the system in the form of compressed air will be,

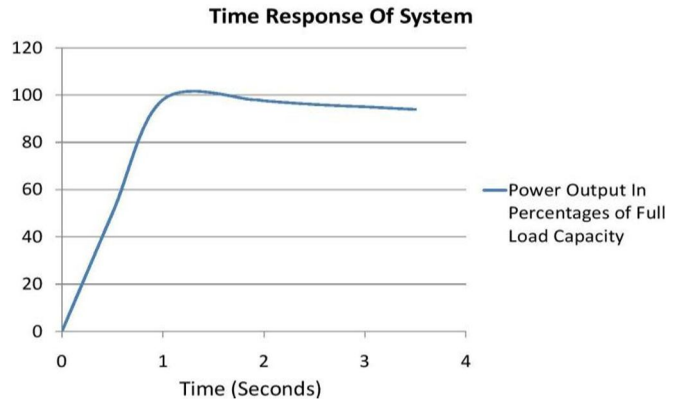
Stored Energy = 612 / 2.83 = 216 times

Hence the proposed system will store 216 times of consumed energy (16.5 KW) by compressed air method.

Stored Energy = 216 x 16.5 =3564 KW

This system can also be used to fulfill the peak power requirement by increasing the speed of weight movement.

Graph representing the Response Time of the System



From the system calculations, it is found that this system has an efficiency of about 90% and can respond with full power in less than 1 second. This system only consists of linear motions of suspended weight due to this the wear and tear of the system is negligible and this system can have a life of about 50 years.

V. CONCLUSIONS

This paper has proposed the use of combined gravity and compressed air energy storage systems. This system acts as the hybrid energy storage system for enhancing the energy storage capabilities. Compressed air energy storage provides bulk energy capacity, while gravity energy storage is used to increase the system's ramp-rate.

We found out some of the advantages as well as disadvantages of using our energy storage system. These are discussed in the below points.

A. Advantages

1) This system has high efficiency of about 85-90%.
2) This system has long life of about 50 years
3) It protects the environment because of no carbon emission.
4) Very simple for construction as well as for installation .
5) This system is very Versatile and can be implemented anywhere.

B. Disadvantages

1) The system is only economical for large scale systems.
2) This system cannot be used for domestic purposes.

VI. ACKNOWLEDGEMENT

We take the opportunity to express our cordial gratitude and a deep sense of indebtedness to our guide Prof. Rajeshri Patil for the valuable guidance and inspiration throughout the project duration. We feel thankful to her for her innovative ideas, which led to the successful submission of this paper. We feel proud and fortunate to work under such an outstanding mentor in the field of Energy Storage Technologies. She has always welcomed our problems and helped us to clear our doubts. we will always be grateful to her for providing us moral support. We would also like to thank Mr. Mane (HOD, EE) and all other faculty members, and all non-teaching staff of the Department of Electrical Engineering for their valuable co-operation. We would also like to thank our family, friends and well-wishers.

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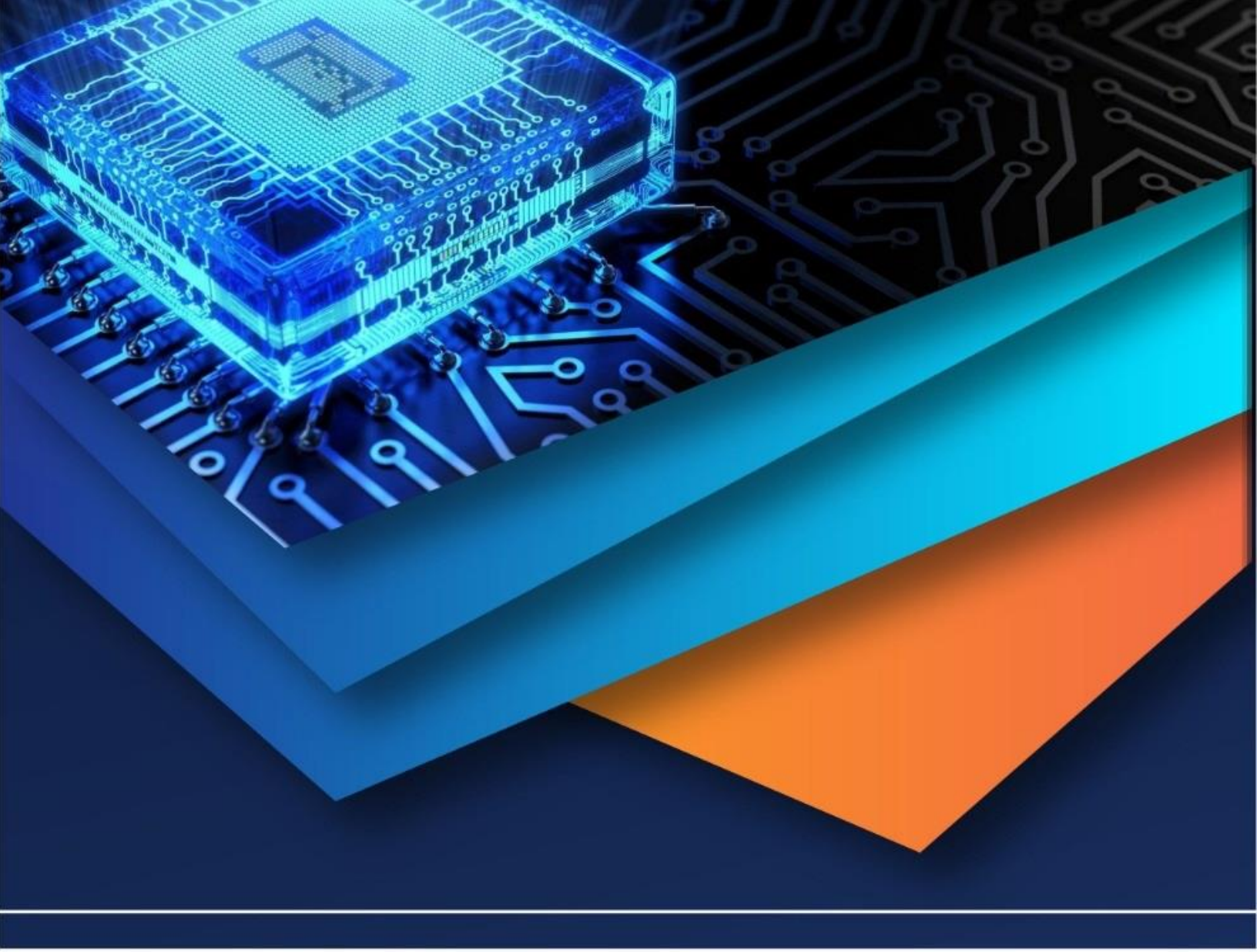

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