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Design and Analysis of Spinning Reserve Gravity HydroEnergy Storage Technology

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Abstract— Southern region of India has more peak and valley on its geological surface which leads more waterfalls. Sustainable energies are trending now due to zero emission power generation. Earth is gifted by natural energy resources every routine of time. Energy storage system for combining all the resources provides uninterrupted power supply to year around. India assures reduction of Green House Gas emissions intensity per unit gross domestic product 35% below level of year 2005, using sustainable energies in generating power to Grid. The intermittency nature of energies affects the stability of grid can be avoided by energy storage system. Energy storing system also solving the extension of power grid, increasing percentage contribution of sustainable energy in power generation, and tallying demand, and supply of energy. Technology implementing for storing power still needed more new experiments to improve the interest on development of sustainable energy generation. Pumped hydro storage is bulky potential storage technology commonly used, however power generation in low water level due to depletion of monsoon, current frequency lag for pumping and reserve spinning are achievable only by gravity hydro storage. This research technically designs and testing the proposed model of gravity hydro storage in SIMULINK analysis tool for Kadamparai location at TamilNadu, India. The optimum design of cylinder and piston are analyzed by ANSYS WORKBENCH also dynamic modeling analysis of hybrid sustainable energies with proposed gravity storage is done. Hybrid model with energy storage can implement in large and small hydro power houses for year around generation. This paper also suggesting model makes all abandoned mines as zero emission energy batteries.

Keywords—hybrid gravity energy storage, kadamparai sustainable, optimum design, Simulink, Ansys workbench.

I. INTRODUCTION (*INDIAN SUSTAINABLE ENERGY STATUS AS ON JULY ,2020*)

India's Intended Nationally Determined Contribution (INDC) builds on its target of installing 175 GW of sustainable energy (SE) capacity inclusive of 100GW solar and 75GW wind by 2022 also committed to further increase in SE capacity addition target to reach 450 GW as the stronger climate action plan. Further nation has made guarantee to boost their contribution of nonfossil based installed power capacity to 40 percentage (%) by 2030 [1].

Total installed capacity of Renewable energy is 87669.19 MW includes 35122.33MW solar, 37829.55MW wind ,45699.22MW hydro and 4688.16MW small hydro power (lesser or equal to 25MW) [2]. Nation is gifted with massive SE potential. As on January 2020 estimated potential of solar power 748.99GW, wind power 695 GW (measured 120 metres above the ground level) and small hydro power 211.33GW (up to 25 MW) [3]. Hydro power and renewable energy shares 13.1% (45.699 GW) and 23.62 % (87.669GW) of total installed capacity, respectively. Total potential of 2,41,844 MW hydro power including pumped storage scheme, only 45,699.22 MW is been utilized. Ministry of Hydro Power stated that identified potential of Small Hydro Power generation capacity in the country is 21133.62 MW from 7133 identified sites. Installed Small Hydro Power capacity is 4688.16 MW. At present, up to of 25 MW capacity hydro power is termed as renewable energy source, larger capacity hydro projects are still included in conventional energy sources. Nation classified existing hydro projects are four types: (1) Purely run of river schemes (3891MW) without pondage,(2) Run of river (16,206 MW) scheme with small pond storage daily or weekly based,(3)Storage scheme (20,517 MW) with reservoir to store excess water during heavy flow and consumption for low flow periods, and (4) Pumped Storage (4,785 MW) schemes which has upper and lower reservoir, water flows from upper reservoir to lower reservoir during generation and reverse during pumping. As on 2019-20 Northern, Western, Southern, Eastern, and North east regions of India has 245,101,249,84, and 33 numbers of units of hydropower plants, respectively. Southern region has highest number of hydro power plants [4]. Least operational cost and better access to many power grid systems makes increase of demand in SE. International usage of SE in all sectors raised by 1.5% relative to 2019. Wind and solar PV power generation increased 3 % compare to last year. Share of SE in worldwide electricity generation increased to 28 % from 26 % of previous year. Variable SE met a higher share of electricity demand during 2020 [5]. Energy Storage (ES) process which converting electrical energy from numerous stored forms like thermal, mechanical, chemical, electrical, and magnetic whenever needed. Scale of ES ranges from micron sized circuit to pumped hydroelectric reservoir that store the equivalent of GWh of electrical energy [6]. PS is lesser capital cost per unit energy, higher potential, long period, higher efficient, and matured technology which regain 85% electrical while conversion. Pumped hydro storage leading the highest rating than all ES, Necessitate the energy management, frequency control and provision for spinning reserve. Energy and power density lie between 0.5 to 1.5-Watt hour per kg [7]. Hydro turbine and governor model simulation were examined and evaluate the performances of the system from single machine infinite bus system to 20 generator large system [8]. Proposed model economic and environmental view of hybrid PV, wind, biogas, and fuel cell renewable energy system analyzed for standalone and on grid application also cost controlled flexibility of system inspected [9]. MATLAB Simulink analysis on pump as turbine for Water Distribution Network and inverter-based speed control to flow act as pressure relief system tested. Wind and PS hybrid system on remote island given various feasibility in ES technology [11]. Wind, solar, hydro hybrid model analyses in Simulink tool and Fourier amplitude sensitivity text method validation for existing model neatly elaborated also all the parameters involved in PS integrated with hybrid power discussed. Unify model of hydro turbine governing system and generator explained for vibration raised in shafts [12]. Dynamic modeling of hybrid system which replaced hydrogen generator by PS tested in MATLAB Simulink, regulated the power during charging and discharging of battery storage [13]. Most suitable combination of renewable hybrid system with PS studied and found that energy efficiency always more than 80% [14]. Feasibility study of seawater pumped storage system showed 1000MW PS plant eliminate 1000MW thermal power [15]. Mountain gravity energy storage has been solution between long term and short-term energy storage where height directed the installed capacity also recommended model for standalone power system study was useful for further seasonal storage implementation [16]. Numerical study of groundwater exchange through the transmissive porous medium increased the efficiency also uses of open pit mines for underground pumped storage discussed [17]. Regulating market service price with optimal study of wind, solar, hydro hybrid with pumped storage proposed model explained revenue losses control also six modes of PS operations were exposed system mathematically [18]. Cat swarm optimization tool used for proposed hybrid model of solar, wind, and gravity storage identified unique energy storage system [19]. This paper proposed design and analyses of

hybrid model for wind, solar Photovoltaic, and gravity hydro storage to solve the issues addressed by India at Kadamparai pumped hydro storage location. This is first novel approach in India combining hybrid of renewable energy for pumped storage with gravity hydro storage to stabilize the Grid also make the plant is spinning reserve and rectify problem of frequency lag in current withdraw from grid for pumping. Also, this model saves the motor -generator coil windings from frequent burning. MATLAB Simulink and ANSYS software's used for analyzing the hybrid model and optimize the cylinder size used for gravity hydro storage, respectively.

II. POTENTIALS AND PARAMETERS OF SELECTED LOCATION FOR CASE STUDY

Kadamparai pumped hydro storage (KadaPH) located in (10.3896° N, 77.0435° E) TamilNadu, Southern Region of India, constructed between Kadamparai river and Aliyar river as shown in Fig. 1. Powerhouse consist of 4 unit of reversible Francis turbine each generate 100 MW power at 500 revolution per minutes, mounted 200 metre below the ground. Net head of Pump and Turbine mode are 381 m and 341 m, respectively. KadaPH designed to operate on schedule of seasonal, weekly, and daily basis. Power generating turbine mode from morning to evening and during nighttime and holidays pumping mode draw power from Grid 110 MW for each pump, forms load pattern to KadaPH. Water taken from Kadamparai Dam and discharge to Aliyar Dam for power generation and same water return to Kadamparai Dam during pumping mode. Turbine and Pump performance per hours in powerhouse stated in Fig.2. Total duration for turbine and pump per day per annum is 4 and 5 hours, respectively. Four units of turbine runs for 1460 hours duration per year generate 584 MU also four units of pump runs for 1825 hours consumed 803MU (652MU in case of monsoon depletion) and stored the 21608 Million cubic feet per year. Pump mode always depending upon grid due to insufficient power. Low frequency current (below 49 Hz) draws from grid affects the winding of the motor-generator.

Solar and wind potential for the KadaPH is shown in Fig.3 and Fig.4 respectively, indicated that Kadamparai location is suitable for proposed model of hybrid of Solar, wind, and pumped hydro storage. Past 14 years data of KadaPH performance for power generation and power consumption shown in Fig.5 which enumerate the data to design the hybrid model.

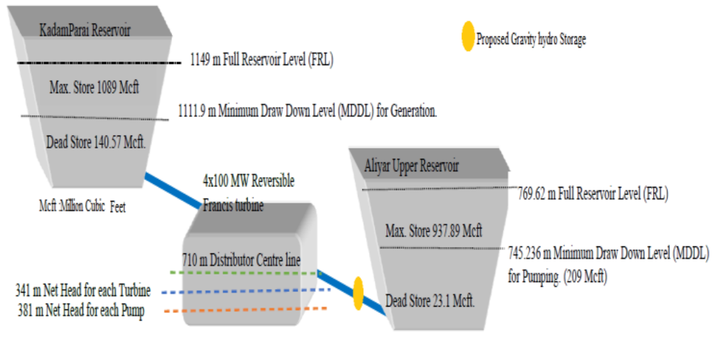

Fig.1. Kadamparai pumped hydro storage

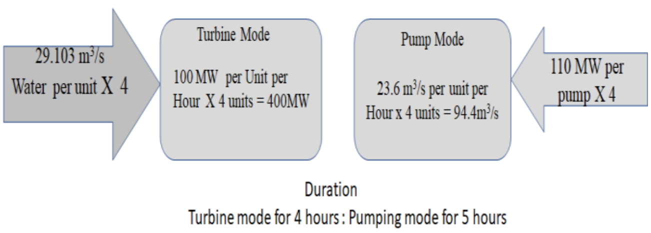

Fig.2. Turbine and pump parameters per unit per hour

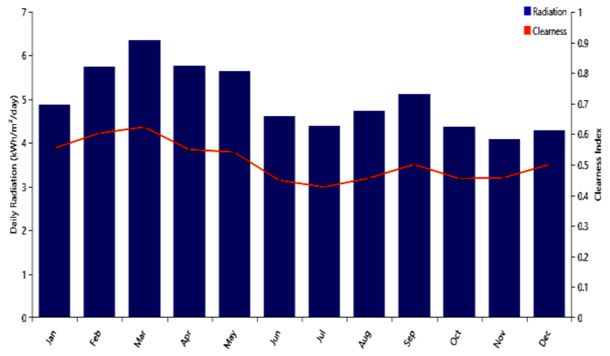

Fig.3. Solar potential at KadaPH from Homer

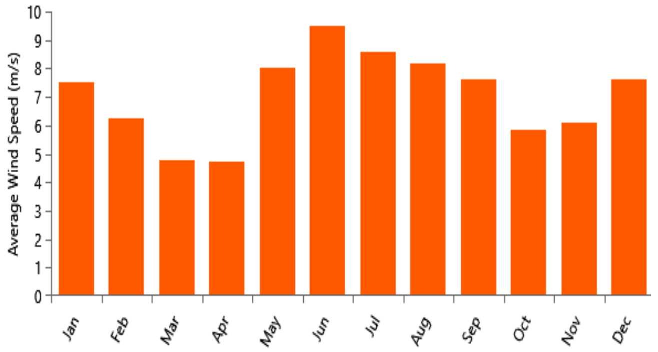

Fig.4. Wind potential at KadaPH for 120 m above the ground level

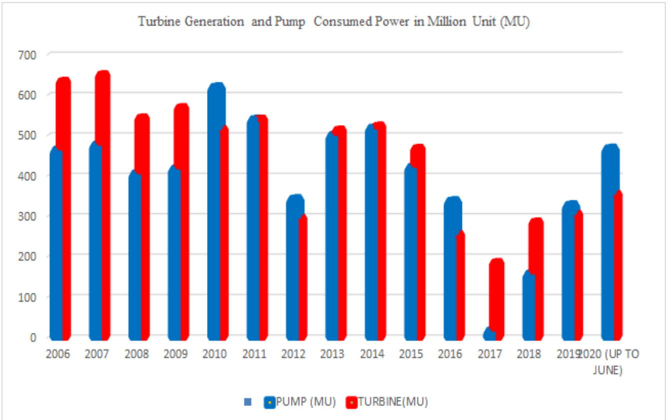

Fig.5. Power generation and consumption during turbine and pump mode

III. PROPOSED HYBRID MODEL FOR SELECTED LOCATION

MATLAB Simulink used to connect the solar, wind, and pumped hydro storage as hybrid model. Hybrid model developed with all practical existing data given as input parameters. 50 MW nominal power of solar and wind connected with existing pumped hydro storage shown in Fig.6.Also Table .1 verified for the power shortage at peak demand for the next 10 years.

A. Solar PV farm parameters

Solar irradiation related to temperature, partial shading and MPPT algorithm and buck-booster DC-DC converter and DC-AC inverter used to interact with grid. Product value of solar irradiation, efficiency of solar panel, and area covered by the solar panel used for nominal power of Solar PV. 50 MW power with least efficiency and partial shading within the specified time range defined by Start and Duration

TABLE I. POWER ON DEMAND FOR NEXT 10 YEARS

Energy Requirement (GWh)				**Peak load (MW)**		
Region	***2011-12***	***2016-17***	***2021-22***	***2011-12***	***2016-17***	***2021-22***
North	294841	411513	556768	48137	66583	89913
South	294860	409805	550022	47108	64349	84778
West	253443	380068	511659	40367	60433	80485
East	111802	168942	258216	19088	28401	42712
North East	13329	21143	36997	2537	3760	6180
Total (All India)	968659	1392066	1914508	152746	218209	298253

parameters, output is set to 'Factor=0.7'. Outside the specified time range output is kept at 1.0.

B. Windfarm parameters

The basic wind farm model used to generate power using a linear relationship between the nominal wind speed and nominal power. When the wind speed reaches the maximal value, the wind farm trips from the grid. When the wind speed is between the nominal speed and the maximal value, the power is fixed to 1 per unit.Wind data profile from collected from National Institute of Wind Energy(NIWE) feed into the system via lookup table. 50 MW wind power with efficiency loss and worst wind speed cases are taken for countability.

C. Pumped hydro storage plant parameters

400MW power generating turbine mode and 440MW power consumption pumping mode subjected to the hybrid simulation. Due to reversible action pump mode is active whenever the grid demand managed by wind and solar hybrid also during nighttime and holidays turbine activate to pump. Fixed and various speed pump operation with synchronous and asynchronous generator respectively taken for simulation shown in Fig. General head loss like entry, friction, turbine loss pump loss and generator loss are considered for hybrid model. The following parameters of hydro plant used for calculation.

Turbine efficiency (ηt) = 0.92

Generator efficiency((ηg) = 0.98

Pump efficiency (ηp) = 0.92

Motor efficiency(ηm) = 0.95

Efficiency of Turbo/Generator(ηtg)= 0.92

Efficiency of Pump-Motor(ηpm)= 0.855

Turbine Discharge per unit/hour = 29.103 m^3/sec
Total Discharge for 4 unit/ = 116.41 m^3/sec

Pump Discharge = 23.6 m^3/sec
Discharge for 4 unit per = 94.4 m^3/sec

Speed of the BHEL made reversible Francis turbine 500 rpm operating between the net head of 341 m and 381 m for turbine and pump, respectively.

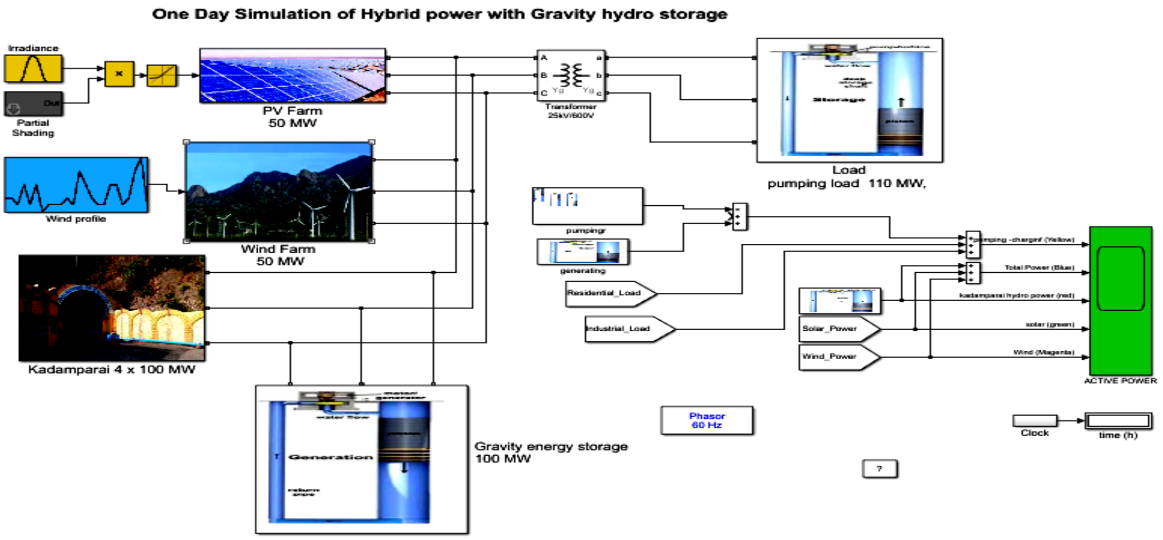

Fig.6. Proposed hybrid model for solar, wind, pumped hydro storage and gravity hydro storage

IV. DESIGN FOR THE GRAVITY HYDRO STORAGE

Monsoon depletion and frequent intermittency of sustainable energy completely disconnected the plant from uninterrupted power supply to grid. To solve this problem most of the hydro plant must be designed with reserve spinning power capacity storage technology. Comparatively pumped and Gravity Hydro Storage (GHS) is cheaper, long lasting, more efficient than all other energy storage technology. Hybrid model of GHS structure diagram explained in Fig.7. GHS stores hydraulic potential energy by pumping and lifting a bulky mass (BMS) against gravity, during surplus power used from sustainable energy also conversion this energy into electrical power when pressurized water discharged back through turbine. Overall plant capacity in megawatt hour dependent on radius, density of the BMS, and height of water column lifted. Radius of the (Granite) BMS is single parameter behave as pivotal variable in this storage technique. The following design consideration used for analysis: Fourth power of radius directly proportional to the capacity. Construction cost is increased with square of radius. Cost per kilowatt hour inversely proportional to square of radius. Length of BMS is twice than radius. BMS lifted equal to radius level for safe design. Sealing placed on BMS must be slightly above the radius distances for steadiness as shown in Fig.8. Energy capacity

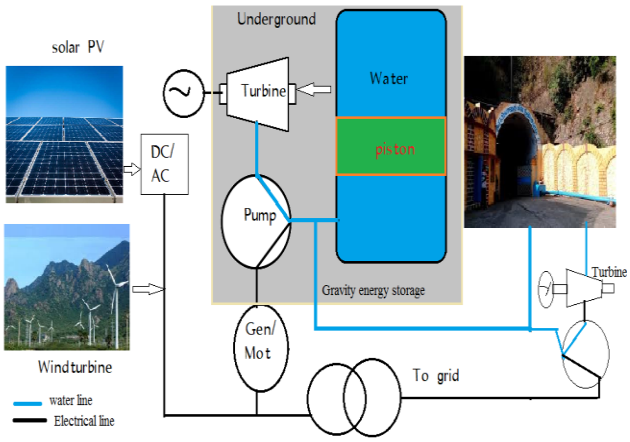

Fig.7. Hybrid structure layout for gravity hydro storage.

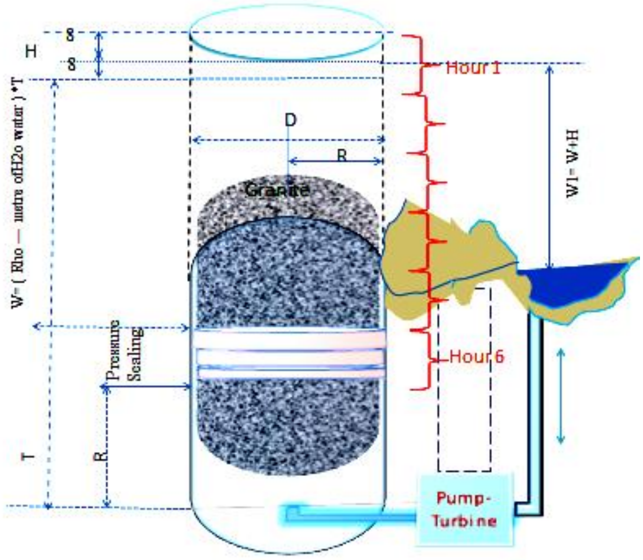

Fig.8. Gravity hydro storage design for reserve spinning

100 MWh (3.6e+11 Joules) generating for 6 hours continuous operation attention given input in Simulink analysis. Result plot for charging and discharging exhibited in Fig.9 ANSYS software used for optimizing the cylinder structure of GHS. Shell thickness of geometry and material like steel and reinforce concrete given as variable parameter for analysis. Static analysis on cylinder measured the equivalent von-mises stress, total deformation and elastic strain and results are plotted in Fig.10 Elaborated structural design of the GHS referred [20] in Table 2. Implemented for analysis. One day Simulink analysis for the hybrid model has been done and results are displayed in Fig.11.

TABLE II, GRAVITY HYDRO STORAGE DESIGN PARAMETERS FOR ANSYS ANALYSIS

Storage capacity	Diameter of bulky mass (m)	Height (m)	Volume of water (1000 m 3)	Pressure(bar)
0.3 MWh	20	30	500	7
200 MWh	80	120	820	21
1 GWh	150	225	1,340	41
3 GWh	200	275	2,380	67
8 GWh	250	340	5,990	71

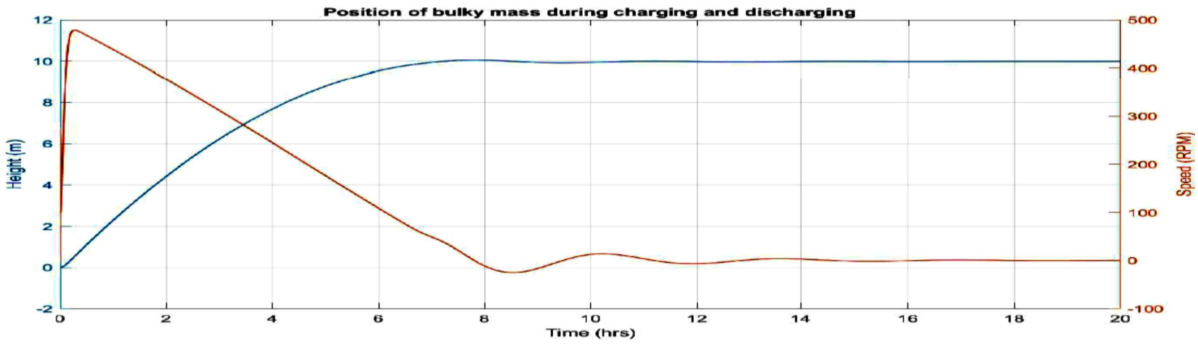

Fig.9. Bulky mass position for 8 hours charging/charging

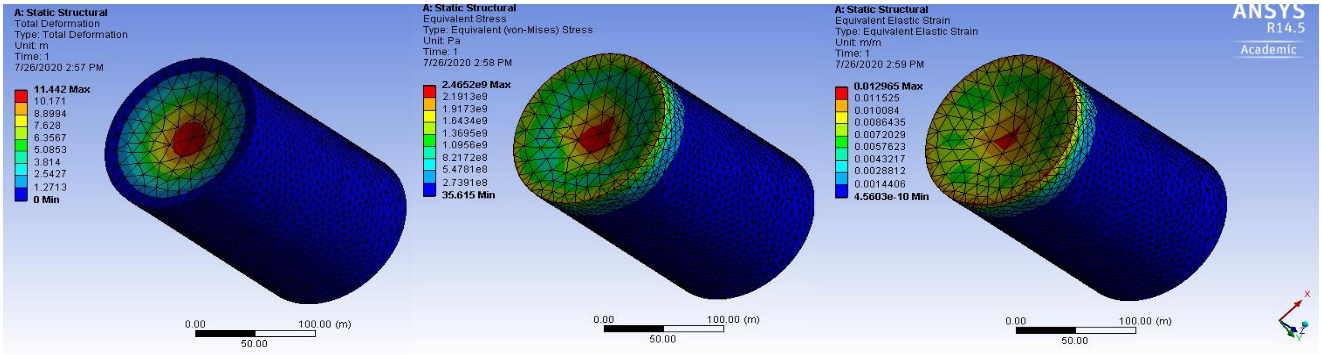

Fig.10. Static structural analysis on cylinder used for gravity hydro storage

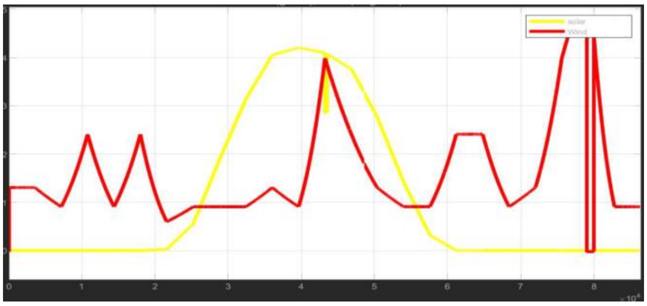

Fig.11. Solar and wind power simulation for 24 hours

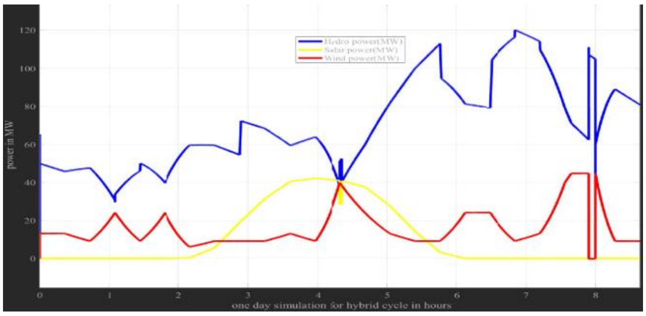

Fig.12. Solar, wind, hydro powers simulation

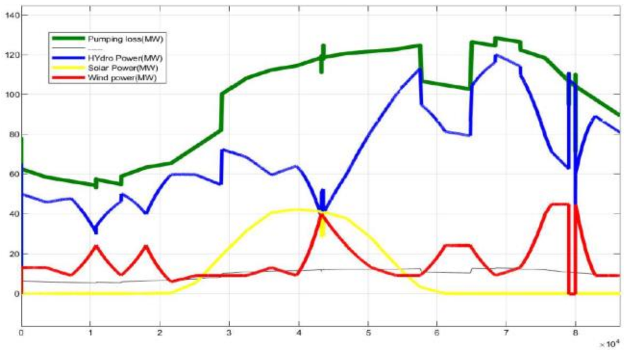

Fig.13. Hybrid simulation curve for pumped hydro storage for 24 hours.

The following energy calculation:

$$E=\text{Area of BMS} \times W1 \times H \times 2725/1000 \text{ (kWh)}. \quad (1)$$

Where,

W1 = stroke length+ height of water lifted above ground level (m),

H =height of water lifted (m),

2725 =energy required (to lift one million litre water at1000m height in kWh).

Using" (1)" commonly calculate energy capacity of GHS at various sizes of plant. Total Dynamic head of pumping mode must consider the height difference between the water supply and storage, friction, and minor head losses in pipefittings, valves, and bends etc. variable and fixed speed of pump operation at various head had been analyzed in Fig.14 below.

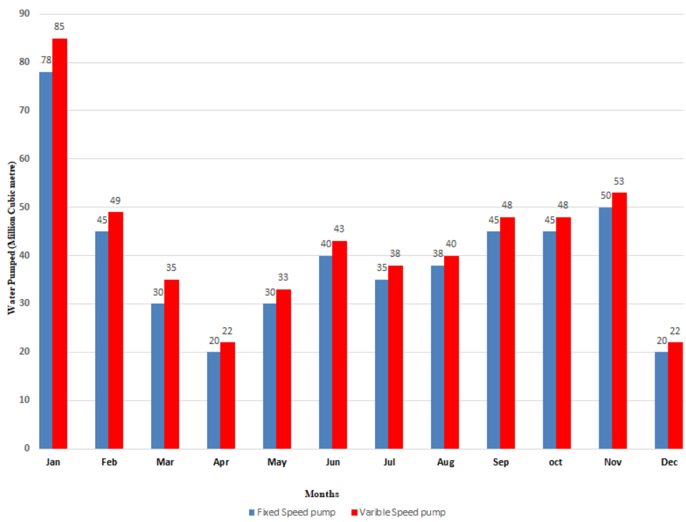

Fig.14. Pump performance at KadaPH.

IV.CONCLUSION

The analysis exposes the solution of issues raised in Kadamparai pumped hydro storage that lag of current frequency during pumping mode solved by variable speed pumping with voltage source converter and hybrid of proposed model connected to grid consciously for supplying instead of withdrawal from the grid.

Next issue addressed in existing pumped hydro storage that insufficient power for pumping mode, water scarcity, and non-spinning reserve capability are solved by implement this Gravity hydro storage model to run the plant year around. We can recommend this proposed model for most of the hydro power plant in India.

Indian Bureau of Mines had identified 297 abandoned mines including 106 Public Sector mines. All mines we can convert as bulky storage water batteries by using as mineshafts for this proposed Gravity hydro storage.

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