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Renewable Energy Curtailment Reduction for California

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Abstract : **One of the major and growing problems in the electric grid is the integration of large scale Renewable Energy (RE) sources with conventional energy sources. Curtailment of RE generation is also an increasing concern in the electric power system. At present, a large amount of both wind and solar energy generation is connected to the power systems in California. This imposes new challenges in the grid and leads to curtailment of renewable energy resources. This paper presents solutions for reducing RE curtailment in California. The optimal energy management problem for minimizing RE Curtailment is formulated as a resource allocation and scheduling problem based on the actual supply-demand scenario in California in 2020. A quantitative study of the RE curtailment reduction potential in California is developed based on various existing and envisaged opportunities in the state. RE curtailment is reduced by first controlling the output of the Hydro Power Plant, then the reduced curtailed energy is exported to other grids who require power especially during peak demand intervals. The remaining curtailment energy is then stored into an Energy Storing System (ESS) typically being Battery. The curtailment reduction algorithm is developed usingMATLAB.**

Keywords— Power Generation Dispatch, Renewable Energy Curtailment, Hydropower plant, Energy Storage System, Uncertainty, Power System Economics, Transmission Congestion.

I. INTRODUCTION

The global climate change mitigation campaign gained good progress after the encouraging Paris climate agreement 2015. The world nations came together committed significant amount of GHG emission reduction targets, to keep the global temperatures well within 2˚C and 1.5 ˚C if possible. Encouragingly, the prices of renewables especially solar have dropped drastically in the past decade and in many countries solar and wind have achieved grid parity, thus making it environmentally as well as economically suitable option. This has resulted in wide scale adoption of renewables primarily wind and solar across the world. The global levelized cost of electricity from solar has also decreased significantly. But then the curtailment of sustainable power sources, especially in wind and sun- powered energy, is getting increasingly far-reaching[1].. As wind and sun energy advancement grows the nation over and penetrations rise. Curtailment can influence the income and thus the profitability of wind and sun projects. With increasing RE penetration, the intermittency and non- dispatchability of renewables bring in unpredictability on the generation side and thus unreliability in the power system. The forecasting of RE is also a challenge. The problem of RE Curtailment is expected to become more prominent as the RE penetration is expected to increases significantly in thefuture.

There are many different definitions of curtailment and there is no standardized way to measure it [1]. In this paper, the curtailment is characterized as a decrease in the output of renewable resources from what it could some way or another produce. Curtailment can result when administrators or utility order wind and solar-based generators to lessen output to limit transmission clog. But it can also occur when there is an over-generation during light load periods, transmission congestion, lack of transmission access, and voltage and interconnection issues [2]. To maintain the frequency at particular limits for small isolated grids and other system balancing challenges, curtailment results in suchcases[3].

Curtailment is one among numerous instruments to keep up the system-energy balance, which can likewise incorporate grid capacity, encourages energy storage devices. Choosing which technique to utilize is principally a matter of financial aspects and operational practice. "Curtailment" today doesn't mean what it did in the mid-2000s. Two big changes in the electric domain have molded curtailment practices since that time: the utility-scale arrangement of wind power, which has no fuel cost, and the development of power markets. These concurrent changes have prompted new operational difficulties however have likewise extended the variety of market-based instruments for tending tothem.

The fundamental goal of all initiatives is to reduce GHG emissions. California has set a decarbonization goal of cutting emissions to 40% below the 1990 levels by 2030 and 80% below the 1990 level by 2050. The California Global Warming Solutions Act 2006, created the multiyear program to reduce GHG Emissions.. In fact, California has many policies and laws to meet ambitious targets. California has good EV penetration and Solar PV installations and with its energy policy has become a global model in climate change mitigation efforts. California has the 2018 law, requiring all of its electricity to come from carbon-free sources by the end of 2045[4]. The EV market adoption in California is around 8% annually, whereas EVs account for only around 5% of the available vehicles. Although, there is a significant reduction in GHG emissions from energy sources with the advent of renewables sources like wind and solar[5][6]. Emissions from in-state generation are reduced by 35% since 2000. Emissions from transportation, landfills, and other highly potent gases from refrigeration and air conditioning are rising sharply, thus offsetting the benefits [4]. Thus to meet the decarbonization goals, thus there arises the need for identifying opportunities for reducing emissions further. In this paper, we take a look at curtailment reduction possibilities in California which is moving towards a low- carbon future through the boundless utilization of sustainable sources. As wind and sun energy quickly develop, there is a rising worry about times of over- generation and thus curtailment. Curtailment is a simple response; however, it is inefficient and affects the financial certainty of the California power system. A large group of generation side and load side measures can keep curtailment to low levels; however, strategy changes likewise are expected to make curtailment a suitable tool. Most curtailment in the U.S. is a consequence of oversupply or transmission requirements. These are not the ideal use of curtailment, as another system enhances may better address the central issue. Moreover, as per the California Green Innovation Index, the pollution declined by just 1.15% in 2017. Thus recent studies suggest that California can achieve 2030 targets, but may miss out on its 2050 energy targets [4][7], owing to the fact that an annual emission cut of 4.5% is required to achieve the 2030 targets and 5.34% is required to achieve the 2050 targets. Thus California faces significant challenges in meeting its decarbonization targets, it becomes necessary to explore all possibilities of improving the performance of existing RE infrastructure by reducing thecurtailment.

This paper delineates several types of practices for curtailment done for wind or solar generation in the Californian Grid. The scope of the paper is to identify and quantify the potential for improvement The curtailment scenario of the renewable energy generations in California using data from the California Independent System Operator (CAISO) [8], is modeled using MATLAB. The excess curtailed power will be distributed to the loads which are in requirement of excess power. Batteries are used here which offer a greater solution in storing curtailed energy when consumers don't need high energy demand. For this paper, data of 1st Jan 2020 are used which are from CAISO official documentation. The proposed battery charging and discharging characteristics are assumed to be the same as Tesla's Horndale Battery Power Reserve facility in Australia[9]. Here, the entire day of 24 hours has been divided into 288 equal intervals of 5 minutes each.

II. California Energysystem

California is one of the main states to deregulate power in 1996 and set up CAISO to run the grid and its market. California's power system is experiencing a fast change driven by technology, consumer interests, and strict clean energy policy. The old worldview of central suppliers serving the consumers is offering a path to an increasingly decentralized and digitized system, with technological advancements producing and controlling energy with more prominent effectiveness and higher worth. A clean energy system is likewise the key to decarbonizing different segments of the economy, including transportation, the biggest sector of pollution emissions [10]. The supply and demand graph of 1st Jan 2020 is given in Fig.1 and Fig.2.

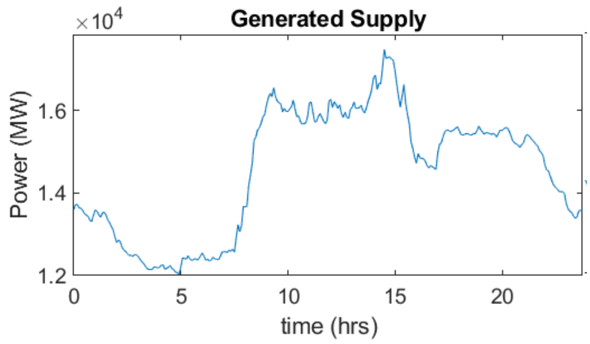


Fig.1: Generated supply

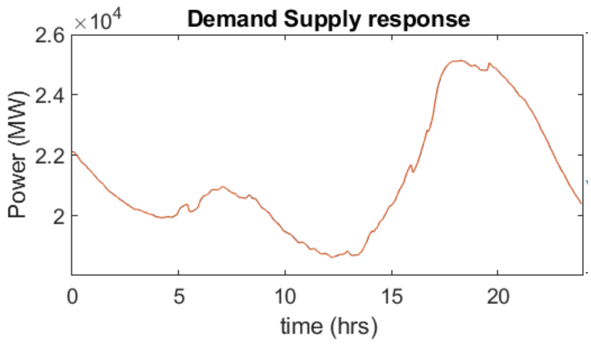


Fig.2: Demand Supply

Due to the high electricity demand because of a large population, California imports more electricity than any other state. In 2018, almost 1/3rd of electricity came from outside the state. In the past, California was importing energy from coal-based power plants. As years passed and when clean energy became a motive it started to import energy from renewable sources. Most of it came from wind energy[11]. The Thermal and imported energy on 1st Jan 2020 is presented in Fig.3 and Fig.4.

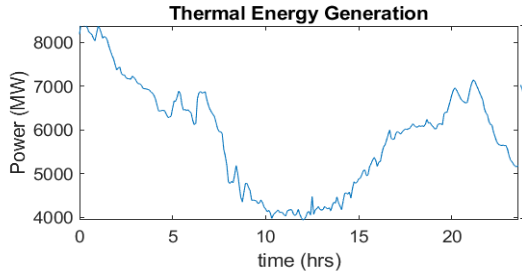


Fig.3: Thermal Energy generation

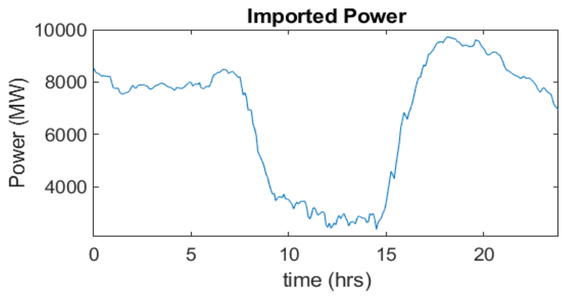


Fig.4: Imported Power to California

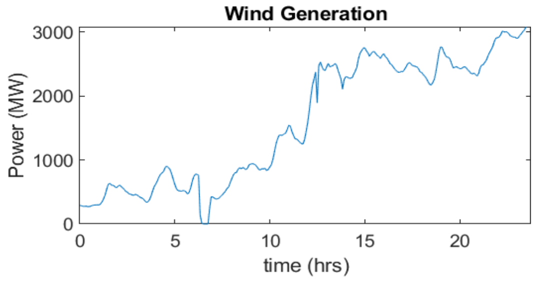


Fig.6: Wind Energy Generation in California

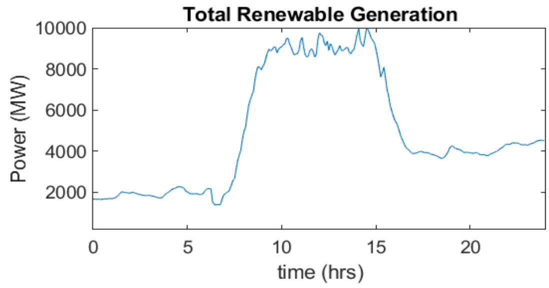


Fig.7: Total Renewable Energy generation in California

California has large energy resources, being among the top producers of oil, hydroelectricity, solar, biomass, and geothermal energy. California has some of the more strict renewable energy goals in the United States. The state is required to obtain at least 50% of its electricity from renewable resources by 2030[12]. The current power demand in the Californian electric grid is 21,366MW as of June 1, 2020. The Renewable sources contribute a great share of 60.2% to the supply overcoming the natural gas which contributes 16%. The batteries, nuclear, and imports altogether contribute around 17% to the supply[13]. The generations from solar, wind and total renewable energy for 1st Jan 2020 are shown in Fig.5, Fig.6, and Fig.7.

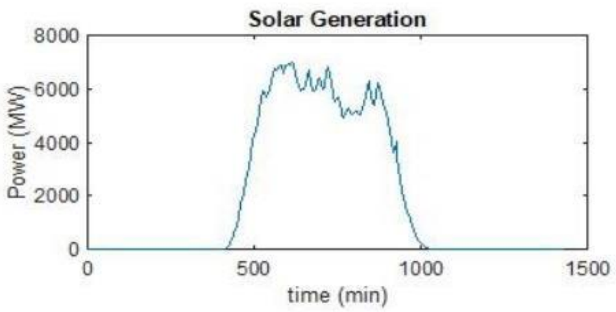


Fig.5: Solar Energy generation of California

Present CurtailmentScenario

The progress to a low-carbon grid gives difficulties as the state consolidates increasing amounts of sustainable power source on to the electric system. Now and again, during the middle of the day, California's sustainable energy can produce more power than is required. This has effects on Demand Response since excess generation is not advisable as the power will bewasted.

Among the renewables, Solar and Wind contribute more to the grid and because of their high availability, this leads to curtailment issues on the generation side. This leads to the shutting down of renewable energy generation. So the ultimate goal of greening the grid has no meaning when conventional sources of generation are only being used. As of April 2020, the curtailment energy from Solar and Wind was up to 318444 MWh, which is a huge amount to be wasted[14]. The demand response of 1st Jan 2020 is shown in Fig.8.

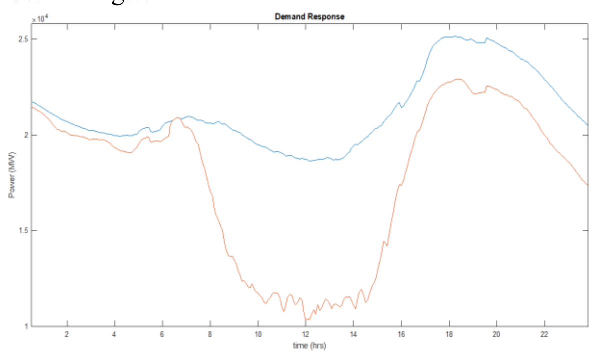


Fig.8: Demand Response of California

Further, this curtailment and demand are plotted with original curtailment and its energy for the same date and is shown in Fig.9.

Renewable Energy Curtailment

As more renewables are integrated into the system, oversupply during the middle of the day, when the sun shines bright, is happening more frequently, and curtailing of solar resources is becoming a common practice. The solar and wind was forced to curtail more than 187000MWh of energy during April 2015. This number rose to double in subsequent years and the majority of curtailment occurred in the months of spring. The spring brought a more challenging oversupply situation for renewable resources [15]. As of 1st Jan 2020, the solar and wind energy curtailment is shown in Fig.10 andFig.11.

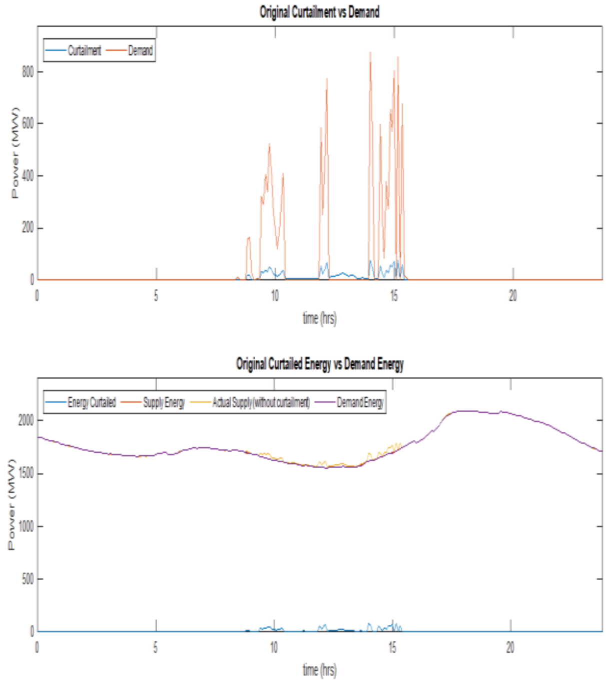


Fig.9: Original Curtailment and Demand Energy

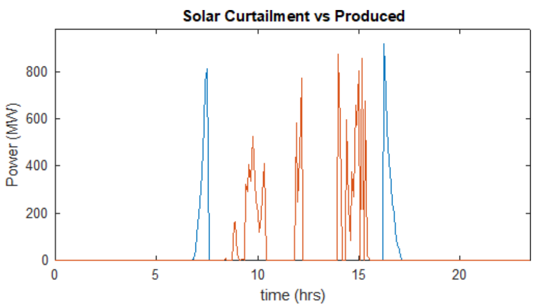


Fig.10: Solar Energy curtailment vs.Produced

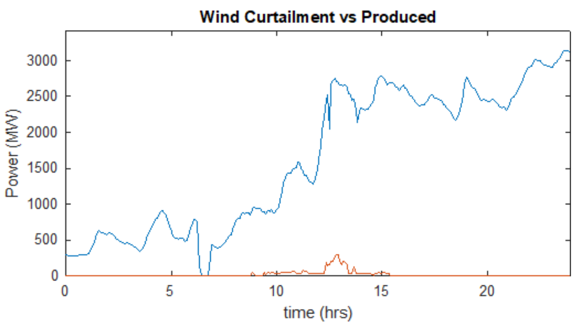


Fig.11: Wind Energy curtailment vs.Produced

The CAISO is working on various effective solutions to overcome the curtailment. However, only 2% of total solar energy in the CAISO was curtailed in 2018, and the CAISO expects only 3-4% of total solar energy to be curtailed in the future [16].

III. Curtailment ReductionMethods

The RE Curtailment minimization problem is fundamentally an optimal energy management problem. In this paper, the optimal energy management problem (for minimizing RE Curtailment) is formulated as resource allocation and scheduling problem, based on the actual supply-demand scenario in California in 2020[17][18]. A quantitative analysis of the RE curtailment reduction potential inCalifornia is developed based on various existing and envisaged opportunities in the state.

Controlling Hydro Power Output

The hydropower generated by California in 2019 is 19.21%, there are about 271 hydro facilities with an installed capacity of 14038MW. There are only two categories of Hydroelectricity in California. One is 30MW capacity plants known as Large Hydro plants and the rest are Small Hydro Plants. But there has been a diminishing of water supply in California for the past 5 years. Consumers were told to reduce the water usage by 25% because of emerging water scarcity. As freshwater is very low in content and with hydropower plants in use, the government won't risk depleting their water resources. The curtailed energy present which is 6822.3MWh observed from Fig.10 can be used to reduce the dependency for power from the hydropower plants in the first place. Instead of relying on the grid for power, this way is more efficient and effective with the reduction of losses due to curtailment [9]. Based on the load forecast and hour ahead forecast values, the power produced from large hydropower plants can be reduced. Hence an optimal saturation point is observed in the curtailed wind and solar energy to ensure hydropower resources to be operated at minimum spike rates, which is advisable for safer operation. The percentage of energy shared from curtailed energy to reduce the dependency of hydropower depends on the degree of curtailment. Hence based on the curtailment data for 1st Jan 2020, the optimal saturation point for curtailed energy is estimated to be 60MWh and the hydro energy output is reduced by 50% from the actual if the previous condition is met. Hence, we can reduce curtailed energy by 17.8%. From the second plot, it is seen that curtailed energy is used to reduce the production rate from hydroelectric power plants. A large amount of power is being used and the remaining curtailed power is observed (Fig.12). Now the total curtailment energy present after reducing the hydro is5607.2MWh.

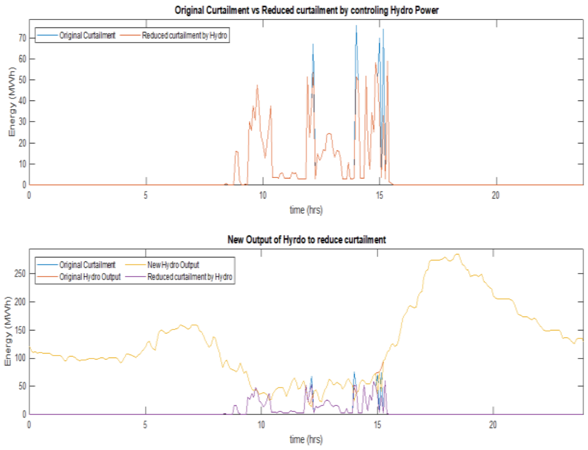


Fig.12: Original curtailment used in Hydropower and New output of hydro to reduce curtailment

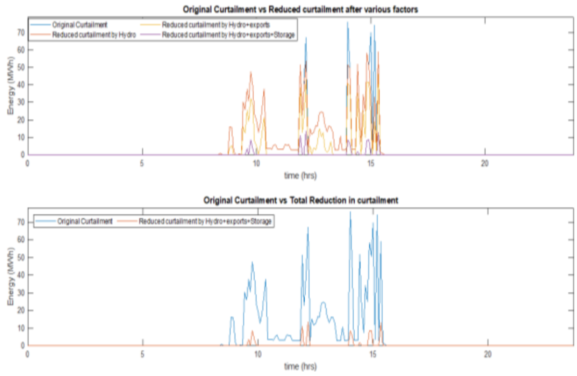
Exporting Power

Exporting energy to nearby grids can help in reducing the curtailment peaks and also can be useful in grid stabilization without the need for any other fundamental changes in the structure of the energy system. California imports most of the electricity. The export rate in California is very less. Since only rough data on export is available, an artificial export limit of 100MW to 200MW has been created which is at par with the real-life limits. The curtailed energy present after using it to stop the hydro plants is used for export purposes. The artificial limit is converted into energy at a 5-minute interval by multiplying it by 5/60 which gives 8.33 to 16.66. The curtailed energy present after exporting is 4485.8MW which can be further used to store in thebattery.

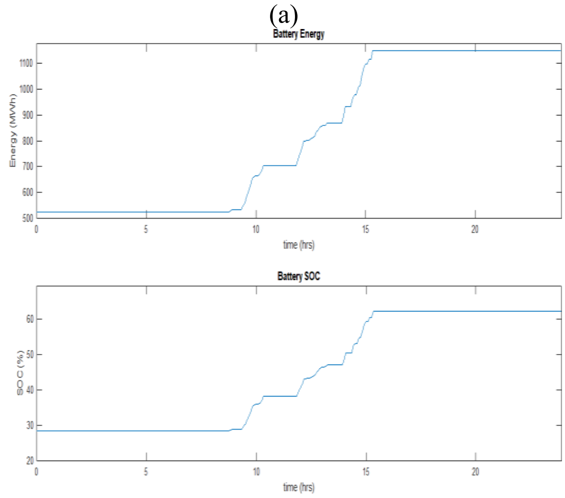
BatteryStorage

Batteries offer one of the good solutions to store excess energy. But their optimal sizing, siting, and costing is the challenge when it comes to storage. The advised battery charging percentage must be from 20% to 80% for safe and prolonged operation of the battery; in this project, the maximum and minimum limits of battery capacity is considered to be 20% and 80%. As for this project, Horns dale Tesla battery farm or reserve which has reduced the servicing cost of the South Australia grid by 90% with a maximum discharge rate of 70MW for 10 minutes and rated power of 100MW [9][19], is taken into account with a storage capacity of 185MWh and ten times of it is taken into consideration for this project to make a significant reduction in curtailment. The Hornsdale battery farm has a maximum charging rate of 40MW, so converting it for 5 minutes gives 3.33MWh. For 10 Hornsdale type facilities, it is 33.33MWh, which is the maximum charging rate considered here. The charging pattern of battery storage of this capacity is: If the charge is less than 50.45%, the charging rate will be quick and if the charge is greater than 50%, slow stepwise charging happens.

The plot for original curtailment and reduced curtailment after utilizing hydro, export, and batteries is shown in Fig.13 (a). Hence the remaining curtailed power is 3396MW. The charging of the battery and its SOC percentage is shown in fig 13(b).



(a)



(b)

Fig.13: (a) Original curtailment vs. reduced curtailment (b) Battery storage energy and SOC.

Battery energy storage system (BESS) will also help in the day-ahead market called spot market where there will be a mismatch of bidding and actual values of generation and demand. The battery storage system minimizes this mismatch by storing excess RE power and supplying power during RE power deficit[20]. BESS also helps improve power quality, black start capability, Island mode operation.[21]

The flow chart for entire Curtailment reduction algorithm which includes all three methods (Hydro power output control, exporting energy and Battery storage) is shown in fig 14.

IV. Possible Solution And Futureworks

The three methods discussed in this paper can be practically used to overcome curtailment, however, there are other ways where curtailment can be further reduced curtailment in proper research is done, this can be a future scope of work in this topic. Dynamic pricing in electricity tariffs can be used to reduce or control curtailment. One way dynamic tariffs can be done by decreasing the cost of energy per unit hour consumed, customers can be encouraged to use excess power during the curtailment period.

This also encourages them to use renewable energy actively instead of stalling them. This is economically effective for both the consumers and producers. Also by decreasing tariffs, renewable energy generation can be made to run by ensuring the "greening the grid" motive is achieved. The excess generated power can be used by the consumers for their daily work other than depending on battery storage. Vehicle to Grid (V2G) is also another method to reduce renewable curtailment[22]-[25]. The electric cars can be charged using curtailed energy during peak energy hours. Instead of depending on the power grid, renewable energy sources can be made to charge the batteries of the car and bikes. Strategic operations of Electric trucks in future when electric truck becomes mainstream: California is one of the major hubs for goods truck parking, which makes it major refreshment and recreation location for truckers. On any day, thousands of trucks are parked in various parking lots and motels in California, so these trucks can be charged during the curtailment or peak hours and can be made to travel during the rest of the day. Special incentives in road taxes can be granted to truck companies who can schedule theirtripsinsuchawaythatallowsthemtochargeduring peak hours. Exporting powers to grid at different time zones: within the USA, the daylight hours vary, so time zone based partnerships can be done among state grids in different time zones to reduce the curtailment especially during the end and beginning of curtailmentinterval.

V. CONCLUSION

In this paper, we formulate an optimal energy management problem for minimizing RE curtailment. The problems are formulated as resource allocation and scheduling problem, based on the actual supply-demand scenario in California in 2020. A quantitative analysis of the RE curtailment reduction potential in California is conducted. RE curtailment potential is quantified based on various existing and envisaged opportunities in the state such as dispatchable hydropower, interstate power exchanges, and utility-scale battery energy storage system. Many such studies are expected in the near future as the world transitions towards sustainable and renewable energy that's intermittent and non dispatchable.

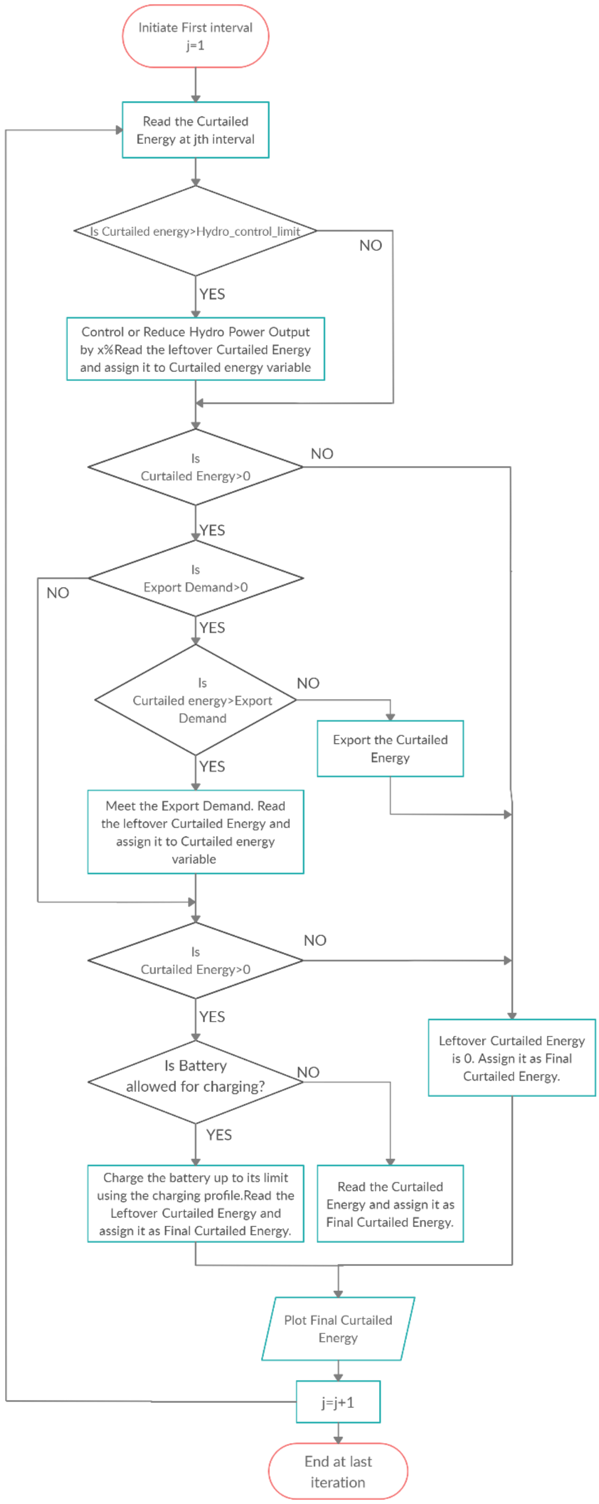


Fig. 14: Flow chart of Curtailment Reduction Algorithm

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