Combination of Energy Storage and Wind Turbine with Conventional Generation Using Scheduling Technique

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***Abstract*—The purpose of this paper is a combination of renewable energy in the particular wind energy with conventional generation by using energy storage optimization algorithm in terms of reduces released output greenhouse gasses, and pollution of the environment which also describe an environmental friendly energy system in order to prevent the effect of global warming. As the project economics, using energy storage in this combination system, have significant advantages instead of conventional generation due to fuel cost. It will be also helpful and makes a profit in case of energy arbitrage, and fuel price. Store and release energy at specific time would have a positive effect on power systems due to variable wind speed and weather condition which is necessarily required ancillary services. Hence, those issues can be done by performing energy storage and scheduling techniques.**

***Index Terms*—optimization algorithm, energy storage, renewable energy**

I. Introduction

It is generally accepted that Energy storage is a very valuable asset for any grid system in particular where renewable energy effectively will be performed in grid to generate electricity include wind energy which is absolutely sustainable source of energy. [1] In fact, in this case the energy storage system creates optimum conditions for energy generation. The energy storage system is able to store and discharge energy at extremely rapid rate where wind energy is not braking and is accelerating at the same time. Hence, the benefit of the energy storage can be saving energy and also voltage stabilization [2].

As matter of fact, sustainable sources have significant advantages compare with conventional generation where sustainable sources contribute to the reduction of CO_2 greenhouse gas emissions. However, using sustainable sources and interconnects to the grid need to maintain in terms of voltage and frequency due to weather conditions. For instance, wind generation, solar generation, wave power generation follows the pattern of weather changes in specific geographic location which obviously cause a changing in voltage-bus and frequency and eventually create problems to interconnect with grid [3].

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In other words, since wind generation is suitable type of sustainable sources, it can be predictable although would not be controllable. the significant reason in terms of difficulty of control wind power would be that when there is a high wind power generation due to variation of mass air and also by considering variation of load-consumption, there will be predicted a gap between generation and demand during time ahead this gap can be deficit or surplus which means by having more generation from wind power, it can be stored.

In contrast, if generation from wind due to variation of wind was low, demand can be support with conventional generators include coal and gas or with some other energy buffer which could be pump storage, hydrogen storage, batteries or flywheels [4]. Finally, in order to evaluate the whole concept of energy storage in relation to wind energy it is important to know how much storage that is need to obtain the desired effect which such information can be used to help choose the most optimal storage technology.

Hence, a variety of technology is available for storage of energy in power system where identifying the most relevant storage solution is necessary to include considerations on many relevant parameters such as: cost, lifetime, reliability, size, storage capacity and environmental impact [4].

Therefore, all these parameter should be evaluated against the potential benefits of adding storage in order to reach a decision on which type of storage should be added.

II. Energy Storage Scheduling Technique

A. *Time Use of Energy*

In this case the important point is time of use of electricity (during 24 hours) in order to reduce the overall cost for electricity. Customer charges the storage during off-peak time period when electric energy price is low, then discharge the energy during times when on-peak (time-of-use) energy prices apply [5] In fact, it will be similar to arbitrage, so in this case the significant things are the prices of electricity to charge and discharge which is based on tariff. For instance, Pacific Gas and Electric's (PG&E's) Small Commercial Time-of-Use A-6 tariff was used.

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Therefore, as shown in Fig. 1, energy prices are about 32 ¢/kWh on-peak (noon to 6:00pm). Prices during partial-peak (8:30am to noon and 6:00pm to 9:30pm) are about 15 ¢/kWh, and during off-peak (9:30pm to 8:30am) prices are about 10 ¢/kWh.

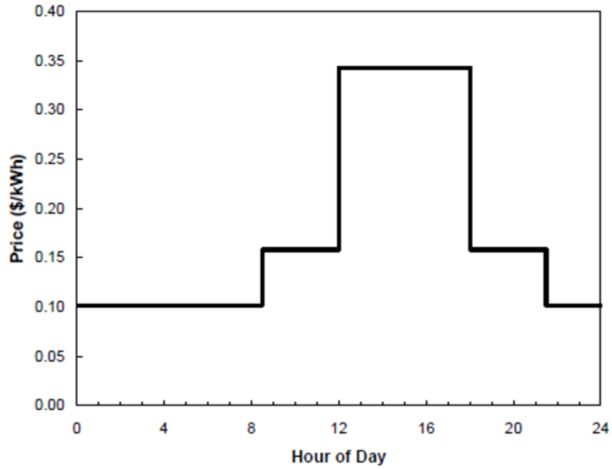

Figure 1. Investigation of demand time [6]

B. *Demand Charge Management*

It can be seen from Fig. 2, the store energy is used to achieve demand during times when demand charge applies. For example, in this case where demand constant in 1MW for three shifts. Firstly, it needs to charge electricity between 00:00 and 6:00 am (during night time). Secondly, neither charge nor discharge which means during 6:00am and 12:00pm is waiting time where both components are identical.

Thirdly, it needs to discharge within 12:00pm and 18 pm to meet demand. Consequently, in this case the storage system is 80% efficient, so to discharge for six hours it must charge for 6/80%=7.5 hours [5]. Hence this technique will be based on applicable tariff.

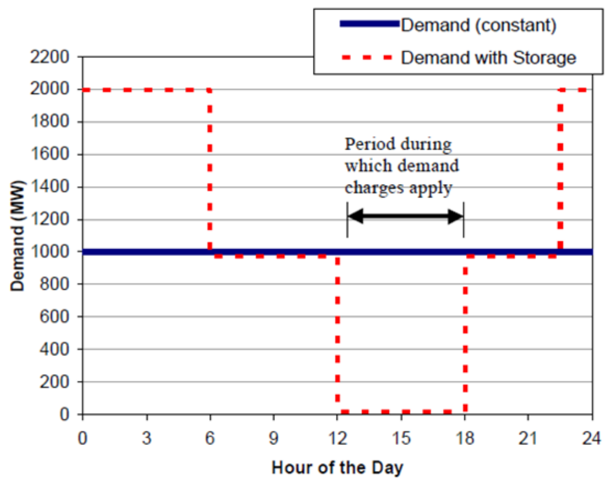

Figure 2. Investigation of release and store energy within hourly [6]

C. *Real Demand Curve during One Year*

The important point is demand curve which is shown in Fig. 3, for one year 2011. It can be seen that during April and may demand will peak in the late afternoon (depends on weather conditions). In addition, during June, July and August demand is also reasonably across the working day (08:00-18:00) with a strong tendency to peak at midday. However, during September and October the daily peak occurs in the evening because of earlier lighting effect [5]. The daily minimum happens around 05:00-06:00 throughout the summer.

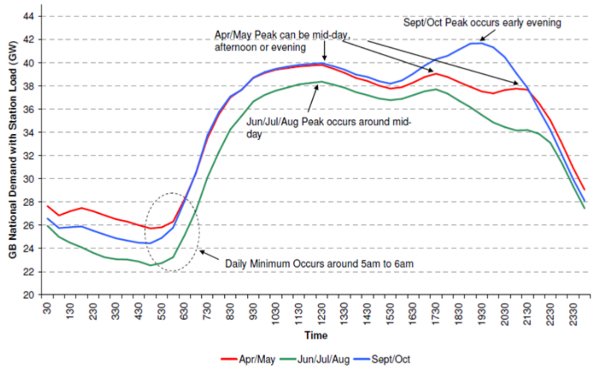

Figure 3. Half hourly demand profile within one year [7]

D. *Energy Storage Technique*

By using pump storage to optimize programs, two optimization programs are required that are linear and non-linear programing. In case of linear programing, water pump will be used to charge during the first six hours of the day (from 0 to 6 am). Then, energy can be produced by hydropower for remaining hours. Hence, the objective function to minimize is [8]:

$$f = \sum_{h=1}^{6} \left(\frac{CBh}{\acute{\eta}}.dNh\right) + \sum_{h=7}^{24}(cTh.\acute{\eta}T.dNh) \quad (1)$$

CB illustrate the electricity tariff for each hour, dN is the water level rise or decrease reservoir for each hours, *CT* is the produced hydroelectricity selling price for each hour, ηB, T are the pump and turbine efficiency and *h* is hour of the day. Obviously, the meaning of this function if there is an increase in reservoir water level (dn>0), the pump station is operating and has a cost *cB* associated for each hour. If, on the other hand, there is a decrease in reservoir water level (dN<0), the system is discharging water from high level to low level and consequently, producing energy that can be sold at a price *CT*. [8] The hourly limits relatively to the pipe flow restrictions are the following from Table I and Table II:

TABLE I. HOURLY RESTRICTION LP

Hourly restriction LP		
Hours	Lower	Upper
0 to 6	0	NQ_{max}
6 to 24	$-N_{Qmax}$	0

TABLE II. HOURLY RESTRICTION NLP

Hourly restriction NLP		
Hours	Lower	Upper
0 to 24	-	NQ_{max}
6 to 24	NQ_{max}	-

In the program of nonlinear case, there is no need to impose pumping and Turbining hours [4]. Therefore, the program will choice the solution which is the best in terms of the significant benefit. Then the objective function for minimization is:

$$f = \sum_{h=1}^{24} [\frac{CBh}{ńB}.\left(\frac{dNh+|dNh|}{2}\right) + CTh.ńT.\left(\frac{dNh-|dNh|}{2}\right)] \quad (2)$$

Consequently, if the water level variation is in high reservoir, the term related to the Turbining is zero [9].

E. Pump Storage with Wind Turbine Technique

Generally, the non-linear programming in winter and summer will be used where the objective function would be non-linear.

$$f = \sum_{h=1}^{24} \left\{ \left[\frac{|\frac{NVh}{dNh}-1| - \left(-\frac{NVh}{dNh}-1\right)}{2} \right] . \frac{CBh}{ńB} . \left(\frac{dNh+dNh}{2}\right) + CTh.ńT.\left(\frac{dNh-dNh}{2}\right) \right\} \quad (3)$$

Nv is the water level rising to reservoir due to wind power for each hour. With the former function, the electricity cost for each hour is not the same as the tariff, but it varies according to the contribution of wind available energy. The wind energy is assumed to have a null cost since for its generation it is not necessary to be supplied. Therefore, for each hour, if all of the energy for pumping water is provided by the wind turbines, it has a null cost. If one part of the energy comes from the electrical grid and the other from the wind turbines, the cost is a fraction of the tariff. For example, if one third of the energy for pumping is provided by the wind turbines for one time step, the cost of energy to pump water in this time step is two thirds of the original tariff. The hourly limits related to the pipe flow restrictions of the system are the same as the previous case (NLP) where the wind component was not considered.

F. Algorithm for the Optimal Regime

Clearly, in this case it can be considered an optimal regime for energy storage in a thermal power system where it is used for daily regulation. First of all to having an algorithm it would be given some information which is: [10]

1) The load carve is divided into m steps with t_j = duration of each step, m = 24h, t_j = 1h

2) For each step the total load demand L_j is given, assumed to be constant during a period t_j.

3) Structure of generation units and generation curve stepwise approximation

4) Fuel consumption curve and fuel cost for each unit

Now, it can be started by using an algorithm with 6 steps:

(i) Compare generation curve with the minimal and maximal relative increments K_{min} and K_{max}. If the optimal regime criterion δ<0, then usage of energy storage [11]

(ii) If the optimal regime criterion is positive, then it is reasonable to increase generation in step with K_{min} by δK_{min}. Where $K_{min}(1)=K_{min}+\delta K_{min}$

It should be mentioned that Es charge may take place in several steps of the generation curve, so it is necessary to check all the intervals where charge is possible [12].

(iii) The energy charged to the central store has to be calculated for all the intervals where energy storage is changing: $Ec= \sum_{j=1m} Ecj$

Then this energy has to be compared with the related energy capacity Es, and if Ec>Es it is necessary to decrease δK_{min} and repeat step (ii)

(iv) It is necessary to decrease maximal relative increment for δK_{min}. Therefore, the new value of relative increment given by $K_{max}(1)=K_{max}(0)-\delta K_{max}$

Step (iv) has to be carried out for all the intervals where $K_j>K_{max}(1)$

(v) Energy discharge from the central store has to be calculated for the entire interval where the storage is discharging: $\sum_{j=1}^{m} Edj$ [13]

Then, this energy has to be compared with the stored energy according to the energy balance:

$$Ed - \epsilon sEc= Ac \quad (4)$$

where, *Ac* is given accuracy. The value of δK_{max} has to be changed and step (iv) and (v) have to be repeated or energy balance will not be satisfied

(vi) The achieved regime has to be checked by the optimal regime criterion:

$$\delta = K_{max}(K)\epsilon s- K_{min}(k) – Ac > 0 \quad (5)$$

If δ>0, steps (ii)-(vi) have to be repeated until δ becomes equal [12].

III. CASE STUDY

A case study has been considered (Fig. 4), in Faroe Island which is located, between the Norwegian Sea and the Ocean. This case study, isolated power system with minimum load 14MW and maximum load 70MW. Existing electricity supply 60% based on diesel generators, 35% traditional hydropower, 5% wind turbine (4MW installed) [9]. In this case it will be considered a scheduling technique in terms of charge and discharge of pump storage, which is connected to the wind turbine and diesel, in order to minimize thermal generation cost in particular in peak demand.

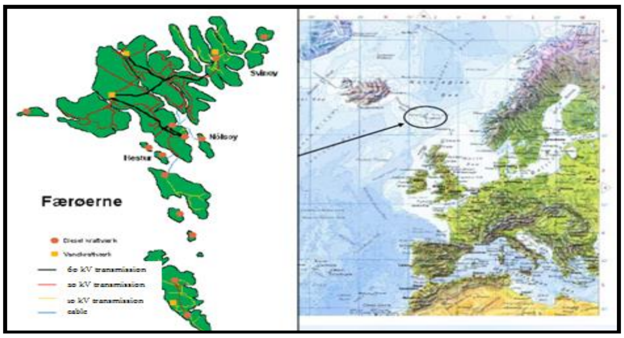

Figure 4. Faroe island [6]

This simulation (Fig. 5), illustrate a combination between wind turbine and pump storage and also conventional generation. It is also demonstrates the investigation of the pumped storage unit for balancing fluctuations from the wind power production. Variable speed of pumped storage unit can improve the dynamic power balance of isolated system and balance power fluctuations from wind turbine [9]

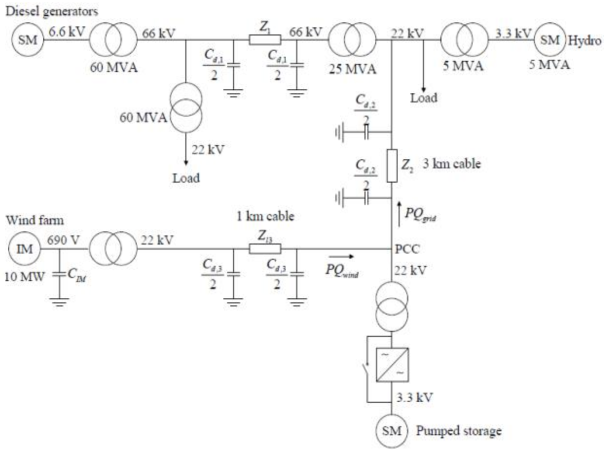

Figure 5. Electrical grids on Faroe island [6]

A. *Proposed Description*

Consideration of Fareo Island simulation is due to understanding the surplus and deficit of demand in order to charge and discharge electricity by using pumps storage during 24 hours. For fallowing and implementing of storage, it needs three components which also have to be considered an algorithm with significant steps to achieve the proposed optimization [12].

TABLE III. INPUT DATA [7]

Hourly	Load MW	Diesel MW	Hydro MW	Wind MW
22:46:00	25.764	20.764	5	10.37
00:15:00	24.008	19.008	5	10.37
01:45:00	23.123	18.123	5	11.29
03:15:00	21.663	16.663	5	13.84
04:45:00	20.245	15.245	5	14.87
06:15:00	26.482	21.482	5	14.88
07:15:00	29.477	24.477	5	13.85
09:15:00	40.123	35.123	5	14.2
10:46:00	42.71	37.71	5	12.89
12:16:00	48.125	43.125	5	12.78
13:46:00	62.41	57.41	5	9.95
15:16:00	66.443	61.443	5	7.68
16:46:00	67.513	62.513	5	6.88
18:16:00	70.375	65.375	5	9.14
19:46:00	60.98	60.98	5	10.81
21:16:00	35.742	30.742	5	9.44

One of the important components is demand forecast for the entire customer. The second remarkable component is output of wind generation forecast and the third is the hydro generation forecast for every day. Therefore, it is going to be taken a real data from national grid, and then it will be tested by using MATLAB simulation of existing grid. Hence, Table III can be illustrated by four forecasts for one day divided by 48 periods with each steps 30 minutes long.

Fig. 6 illustrates the average estimation of the wind generation during 24 hours by 48 periods in each step 30 minutes which is taken in summer season. It is observed that during mid-night and morning time wind generation is high which is suitable to store output of wind generation at this specific time by pump storage.

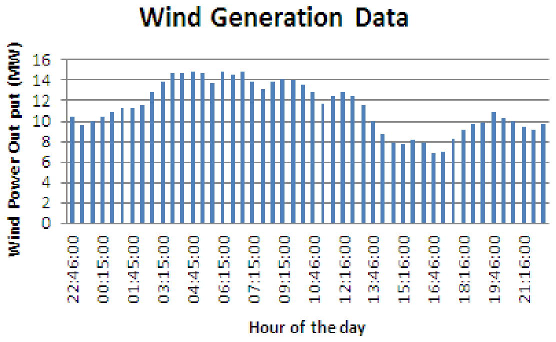

Figure 6. Wind power output data

Fig. 7 shows the significant estimation of daily energy consumption of maximum 70MW per day which is taken in summer season. In addition, it can be seen that the peak load demand in a day on Feroe Island is started around 12pm to 6pm due to daily working hours, and form 6pm to 6am the load profile seems to be low demand.

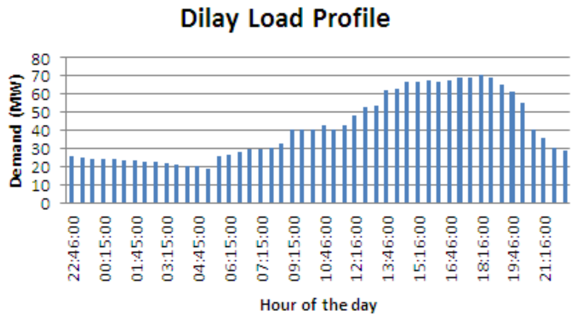

Figure 7. Demand output data.

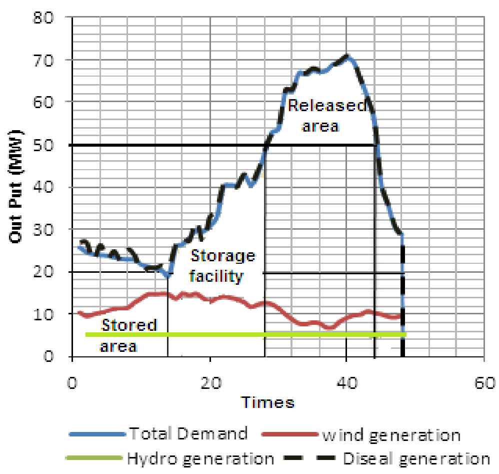

Figure 8. Output of components

B. *Method Principle*

As shown in Fig. 8, this prediction during 24 hours divided by three periods; First period is night time (store energy). During this period, energy is stored in store-facility reservoirs which is water pump station or also can be other sort of energy storage suitable for power storage. In this period wind farm energy and part of the energy produced from hydro generation are stored. The second period is day time (waiting time). During that period the storage facility is filled in order to efficiency (up to some level) and waiting for release. The energy from the wind farm and hydro generators is directly connected and released to the grid. The third period is peak day time (release energy). During this period the entire energy stored in the storage facility is released into the grid in certain pattern [11] Therefore, by using an algorithm in case of this operation of storing and releasing energy during on-peak and off-peak, it can be save money for diesel and reduce CO_2 emission.

C. Generator Principles and Grid Connection

As a matter of fact, Fig. 9 will be shown a cost curve of conventional generation. Obviously, as we can see from this curve by using more generators to support demand, the cost of generators will be expensive because of consuming lots of gases and also maintenance. Therefore, by increasing of generators, the efficiency is going to be down. Hence, in this algorithm, it will be calculated the cost of generators which is connected to the grid. To calculate the cost, it can be used this equation

$$C_i(P_i) = (A + B*P + C*P2 + D*P3)*E \text{ [\$/hour]} \quad (6)$$

where A is the fixed cost (zero output running cost) and B, C and D are used to model the generator's input and output and E is the Fuel cost (expressed in \$/Mbtu)

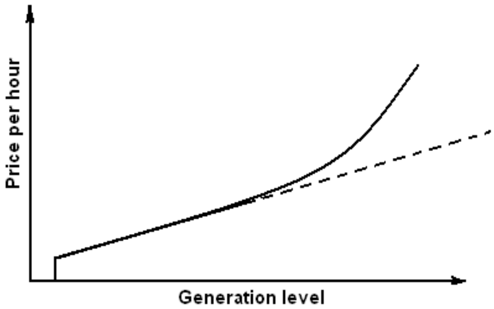

Figure 9. Curve fuel cost in normal operation

It can be seen from Fig. 10 to support the entire demand there will be four diesel generators which the first generator provides 20MW, second and third generators15MW and finally fourth generator provide 10MW. Therefore, each generator is going to be run based on demand respectively where the first generator which is 20MW, is base generator efficiency.

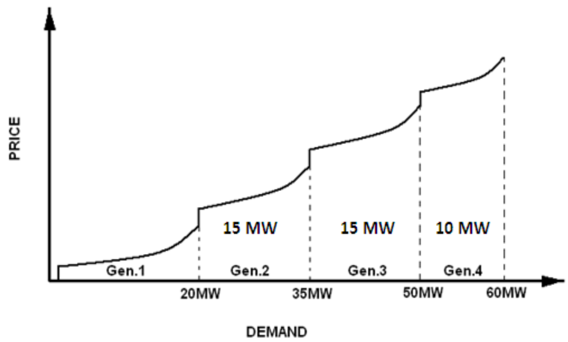

Figure 10. Curve fuel cost based on level generation in normal operation

Therefore, this curve is based on demand since demand is going to be increased, more generators should be run. For instance, if demand will be 50MW, generator 1, 2 and 3 would be run where generator 3 will be too expensive than generator 2 and 1 due to fix cost.

IV. Simulation Results and Discussion

It will be demonstrated the significant algorithm, which is shown in Fig. 11, where considered store and release of energy and price calculation. This algorithm will be programmed with Matlab software.

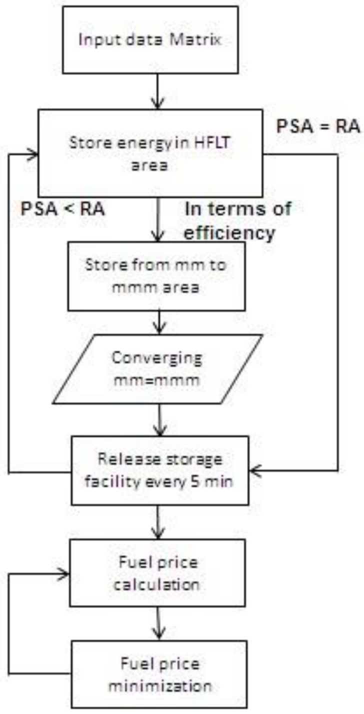

Figure 11. Algorithm structure

This algorithm divided by three parts during 24 hours. As shown in Fig. 12, the first part is storage area where it will be stored with pump storage between 0 and 6am. The second part will be waiting time which means no action would not be happened in order to store and release energy (base on efficiency) which is between 6am and 12pm. The third part is going to be release area where demand is high from 12pm to 18pm which also going to provide from stored energy.

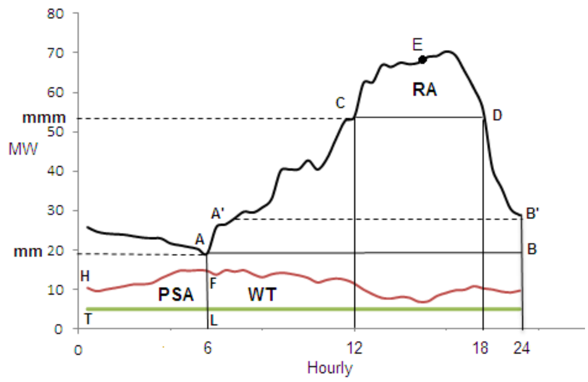

Figure 12. Showing a corresponding to critical point

It can be understood that storing time (0-6am) can be corresponding approximately to point A, where also mm point will be constant. Hence, in this case, algorithm will start to calculate HFLT area where it is store energy. Then, it will starts to calculate the releasing area where significantly it is going to corresponding to the stored area since it would be considered the round trip efficiency about 85% which is going to be used from storage facility [13].

Finally, when the computer calculate ABDEC area, then it will compare with HFTL* 85% area. If HFTL* 85% area is smaller than ABDEC area the program will create more steps to corresponding. For instance, it can be seen from Fig. 10 point A becomes A' and point B will be B'. Hence, the release area will be made smaller which finally the new release area will A'B'DEC and then after calculating again compare to store area (HFTL* 85%). Consequently, in this step both store and release area must be identical (with at least tolerance of 0.2MWh) where in this algorithm mmm point calculates based on mm point.

A. Calculate the Fuel Price of Conventional Generation

In this loop, it will calculate the fuel price of conventional generation in case of peak demand. To support the entire demand (70MW) there are 4 diesel generators which is clearly shown each level for each generators in Fig. 10, wind farm (15MW) and hydro generator (5MW).

It can be seen from Fig. 10, the first generator is base generator to support the significant demand which normally the price is low. Then, the next is generator 1 which is covered initial demand about 20MW. The second generator is support higher demand than pervious about 10MW where in the curve located in 35MW. The third generator will covered until 50MW, and finally, the fourth generator will support the rest of demand more than 60MW (peak demand) where the price of fuel is going to be expensive. Consequently, in this algorithm it will be used cubic cost curve which is mentioned below [14]:

$$C_1(P_i) = (90+7*P+0.25*P^2+0.000005*P^3)*30 \text{ [G1 20MW]} \quad (7)$$

$$C_2(P_i) = (80+7*P+0.25*P^2+0.000005*P^3)*30 \text{ [G2 15MW]} \quad (8)$$

$$C_3(P_i) = (70+7*P+0.25*P^2+0.000005*P^3)*30 \text{ [G3 15MW]} \quad (9)$$

$$C_4(P_i) = (60+7*P+0.25*P^2+0.000005*P^3)*30 \text{ [G4 10MW]} \quad (10)$$

The coefficient is going to be in $/MBtu and also each gallon of diesel is approximately $2.77 which is considered one gallon of diesel fuel is equal to 0.138690 Mtu. Therefore, the coefficient E will be price ($)/MBtu = 2.77/0.138690 = 20$/MBt.

In other words, this algorithm will operate based on each zone which is covered by diesel generators. Then, it can be considered an input for this calculation, the value of demand will be supplied for 5 minutes interval which also will be reacted by this loop. Hence this table consist all the result from each area in MW which must be supplied for every step where linear running considered within this interval.

Therefore, by fallowing above equations, it will be account the spending of dollars for each generator in per hours, so in this algorithm, it will be taken each value from table and put in the formula where the interval taken 5 minutes during half hour which has to be six. Consequently, the spending price for each 5 minutes period and also the entire expenses day are calculated.

B. Final Results

As it can be seen from the result (MATLAB print out) Fig. 13, it is divided 2 parts. The first part of this capture shows the total generation based on demand where light blue area shows the store energy where the part of hydro and wind farm energy stored in nighttime, dark blue area indicates release energy in peak demand and yellow area also shows the release energy where directly will connect to the grid and peak time. The pink area will illustrate the diesel generators where it would be covered the entire demand. The second part will shows the minimum price of fuel where the release energy is operating. Therefore, this implementation can be the significant aim of this algorithm.

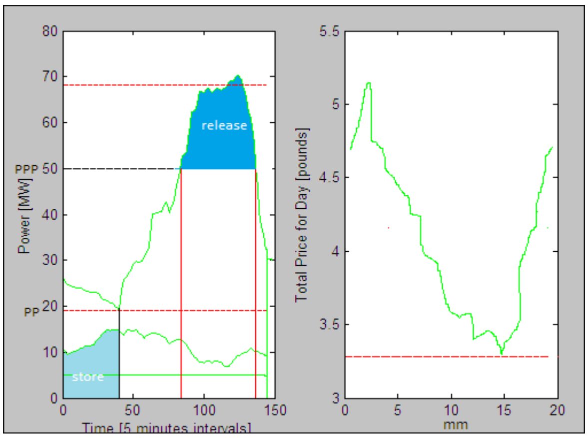

Figure 13. Matlab printout with energy storage

In contrast, as shown in Fig. 14, if it is going to remove store energy where also does not to use algorithm, the peak demand will be covered with diesel generators which means the reliability and save fuel will dramatically decrease.

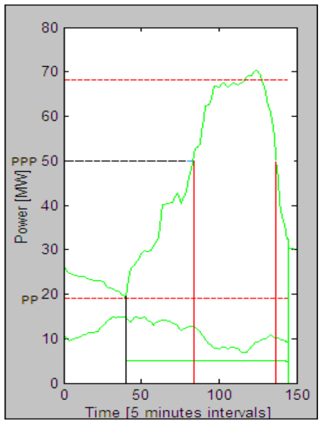

Figure 14. Matlab printout without energy storage

V. CONCLUSIONS

The result demonstrated that a significant saving of fuel cost compare to the normal operation mode. When the storage facility is added to the system the profit is going to be much higher in terms of saving money with energy arbitrage in particular for winter and summer wind conditions. In addition, the general idea of the algorithm would be implemented to make a generation level of diesel generation in order to create the maximum linearization. This system is used pump storage which the round trip efficiency is fixed to 85% with high profit. In other words, in this system CO_2 emission is reduced because by using storage facility in a significant time, it can be used less fuel to burn where in normal operation diesel generators in full load will be consumed for each KW approximately 0.08 gallon per hour which is totally produced 11,294,080g CO_2 per hour. However, using storage facility in peak demand it will be used less fuel and so less CO_2 emission.

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