Utilization of Thermal Energy Storage for reducing Battery Bank Size of Hybrid (Wind-PV) Systems

M.Zamani*, G.H.Riahy** ,N.Abdolghani**, M.H.Zamani**, Gh.Shahgholian*
* Islamic Azad University-Najafabad Branch, Department of electrical engineering, Isfahan, Iran
** Amirkabir University of Technology (Tehran Polytechnic), Electrival engineering department, Wind energy lab., Tehran, Iran

Abstract— **Hybrid systems are becoming popular for remote area power generation applications. Any effort to decrease capital and operating costs, contributes to increase penetration of hybrid systems in power generation systems. In this paper combining of hybrid systems and Thermal Energy Storage (TES) has been proposed for lowering the costs of hybrid systems in hot climate. Since nowadays TES is known as an economical option in various sectors, therefore TES is selected for combining with hybrid systems.**
Optimization results show that, using TES in hybrid systems leads to significant reduction of the battery bank size or consumed fuel by backup systems like diesel generator. Therefore in hot climate, the hybrid systems which equipped with TES will be more economical than the conventional ones.

***Index Terms*— battery bank, hybrid system, thermal energy storage**

I. INTRODUCTION

Hybrid (Wind – PV) systems are widely used all over the world due to their simple construction, and efficient and continuous energy supplement capabilities in comparison with other combination of hybrid systems [1].

Because of intermittent nature of wind speed and solar irradiation, hybrid energy systems are often combined with battery bank or diesel generators. Specially in hot or humid climates that cooling loads like air conditioning causes huge increase in peak electrical demand and therefore in such climate, hybrid systems need to be equipped with a large battery bank or diesel generators to meet the load demand completely. Since the cost of batteries and fuel has occupied fairly large part of the total cost of hybrid systems, thus, decreasing the size of backup system and battery bank can directly reduce total cost of hybrid systems [2].

The principle idea in using TES systems is to shift cooling energy use to non-peak times. They chill storage media such as water, ice, or a phase-change material during periods of low cooling demand for use later to meet air-conditioning loads. Operating strategies are generally classified as either full storage or partial storage, referring to the amount of cooling load transferred from on-peak to off-peak [3].

TES systems are applicable in most commercial and industrial facilities, but certain criteria must be met for economic feasibility. A system can be appropriate when maximum cooling load is significantly higher than average load. High demand charges, and a significant differential between on-peak and off peak rates, also help make TES systems economic.

In this paper, for decreasing the size of diesel generator or battery bank, combination of hybrid system with TES system in hot or humid climate is proposed. Partial storage system is selected as an operating strategy for TES. By partial storage system, it's possible to increase load factor ratio (the ratio of average load to the peak load) of cooling load to unity. In the proposed method, load profile is first modified by considering existence of TES. i.e. the new cooling load profile is calculated and the load profile is updated as sum of the new cooling load profile and non-cooling load profile. Finally, optimal sizing of the hybrid system is performed based on the updated load profile.

A simulation software code has been developed to carry out the analysis for optimizing the size of the components of TES system for a given location. Also a software tool, Hybrid Optimization Model for Electrical Renewable (HOMER) is used for the economical analysis and determining the size of hybrid elements such as wind, PV, battery bank,.... [4]

Optimization results show that in hot and humid climate, hybrid systems that equipped with TES system make it possible to reduce the size of backup system or battery bank.

II. OPERATING ANA CONTROL STRATEGY OF TES

Thermal energy storage systems shift cooling energy use to non-peak times. These systems chill storage media such as water, ice, or a phase-change material during periods of low cooling demand for use later to meet air-conditioning loads. [3]. recently several energy storage technology exist that can be used in combination with energy resources to economically buffer variable rate of

978-1-4244-8930-5/11/$26.00 ©2011 IEEE

energy supply and demand. Thermal energy storage is one of the most important energy storage technologies and, nowadays, increasing attention has been paid for installing thermal energy storage systems in most commercial and industrial sectors. Reducing energy cost and energy consumption, reduction of operating and maintenance costs, improving indoor air quality and also increasing flexibility of operation are some of advantages of utilizing thermal energy storage. In thermal energy storage system, cold is stored in a thermal storage mass. as shown in Fig. 1. The storage can be incorporated in an air conditioning , air cooling or water cooling system in a building [6].

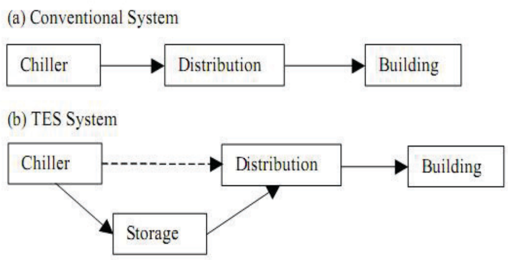

Fig. 1. Shematic representation of cooling system

TES operating strategies are generally classified as either full storage or partial storage, referring to the amount of cooling load transferred from on-peak periods. Strategies for operation at less than design loads include chiller priority and storage priority control [5].

A. *Full storage*

Full-storage, or load-shifting, shifts the entire on-peak cooling load to off-peak hours and usually operates at full capacity to charge storage during all non-peak hours. On peak, all cooling loads are met from storage, and the chiller does not run. A full-storage system requires relatively large chiller and storage capacities and is most attractive where on-peak demand charges are high or the on-peak period is short (Fig. 2).

B. *Partial storage*

In a partial-storage method, the chiller operates to meet part of the peak-period cooling load and the rest is met by drawing from storage. The chiller is sized at a smaller capacity than the design load . Partial-storage systems may operate as load-leveling or demand-limiting operations.

In a load-leveling system, the chiller is sized to run at its full capacity for 24 hours on the hottest days. The strategy is most effective where the peak cooling load is much higher than the average load. In a demand-limiting system, the chiller runs at reduced capacity during peak hours and is often controlled to limit the facility's peak demand charge (Fig. 2). Demand savings and equipment costs are higher than they would be for a load-leveling system and lower than for a full-storage system.

Partial-storage is more often the most economic option and therefore, represents the majority of thermal storage installations. Although partial-storage does not shift as much load (on a design-day) as a full-storage systems, partial storage systems can have lower initial costs, particularly if the design incorporates smaller equipment by using low temperature water and cold-air distribution systems [5].

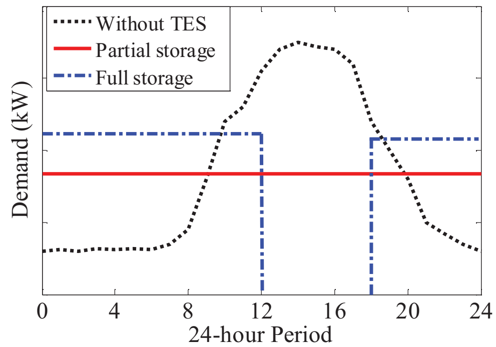

Fig. 2. Comparison of conventional and TES systems [6].

III. HYBRID SYSTEMS

Hybrid energy system is a reliable alternative energy source, because it uses multiple energy resources to create a stand-alone energy source. At sites that are far away from a conventional power system, the hybrid energy system has been considered as preferable [].

These systems exhibit higher reliability and lower cost of generation than those that use only one source of energy [42]. The use of different kinds of energy resources allows to improve the system efficiency and the reliability of the energy supply and reduces the energy storage or backup requirements compared to systems comprising only one single energy resource. On the other hand, with the complementary characteristics between solar and wind energy resources for certain locations, hybrid PV-wind power generation systems with storage banks or diesel generator offer a high reliable source of power[batt].

PV-Wind hybrid systems for standalone applications have the potential to be more cost efficient compared to other combination of renewable energy.

Also as Fig 3. Shows, during the winter season when solar radiation is very limited, wind power can compensate and In case of low wind speed at summer season, PV panels meet the peak load demand.

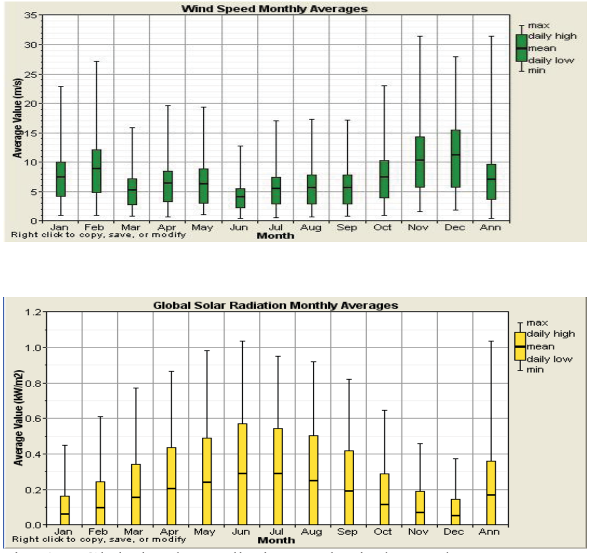

Fig. 3. Global solar radiation and wind speed

IV. CASE STUDY

One of the hot climate areas in Iran has been selected for case study. This area is a suitable case for installing thermal energy storage systems. Fig. 4 shows daily load profile of cooling and non-cooling load of this area. As shown Fig. 4. Maximum cooling load is significantly higher than average cooling load. Also there is a significant different between on-peak cooling load and off-peak cooling load. Therefore thermal energy storage system is cost effective option for electrical load management in this hot area.

A partial storage system is designed and electrical load profile (cooling load + non-cooling load) is modified by considering the existence of partial storage thermal energy. Figs. 4 and 5 show the changes in electrical load profile when system is equipped with thermal energy storage or not.

Hybrid systems including wind-PV-diesel and wind-PV-battery are implemented and theses systems are optimized in HOMER. A thorough analysis of the proposed system with existence and inexistence of TES is presented and Simulation results are compared separately.

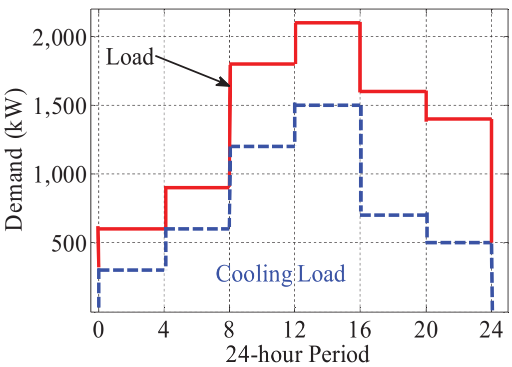

Fig. 4. Daily load Profile (without TES)

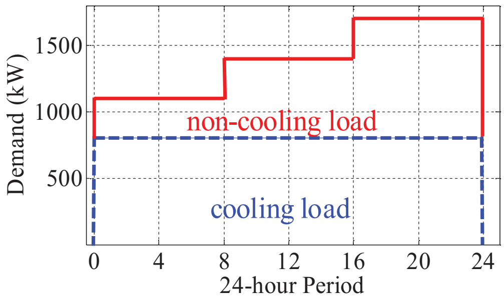

Fig.5. Daily load Profile (with TES)

A. Wind-PV-Diesel

Fig. 6 Shows the power curve of WES30 wind turbine which is selected for the hybrid power generation system under study. Fuel cost is determined 0.4$/liter. Also investment and maintenance costs of PV array and wind turbine are shown in table 1. The initial cost for installing a thermal energy storage system in this area is 650000$. Since the calculation is based on the partial storage strategy of TES, daily load Factor will be unity and daily cooling load profile changes as shown in Fig. 5.

The most economical combination of the hybrid (Wind-PV-Diesel) and (Wind-PV-Diesel-TES) systems are listed in table. 2. The information of this table is suggested by HOMER software.

TABLE I
THE COSTS AND LIFETIME ASPECT FOR THE SYSTEM COMPONENTS []

Component	Unit Price ($/W)	Maintenance cost in the first year %	Lifetime (year)
PV array	4.84	1% of price	25
Wind turbine	3.000	3% of price	20
Battery bank	0.207	1% of price	4
Inverter	0.715	0	10

TABLE II
PROPOSED COMBINATION FOR WIND-PV-DIESEL

Storage System	Wind Turbine WES 30	PV (KW)	Diesel (KW)	Renewable fraction
With TES	6	450	700	80%
Without TES	6	450	900	76%

As presented in table 2, it can be observed that the usage of TES causes a decrease in back-up system size by 200kw. Consequently, during the system operation lifespan, fuel consumption is decreased by 23.6%.

Economic analysis of the proposed system is listed in table 3, where although an increase in initial costs is observed, the overall cost is decreased by 11.3%. Actually, the cost of electricity (COE) is decreased by 0.009$/kWh.

TABLE III
ECONOMICAL ANALYSIS FOR WIND-PV-DIESEL

Storage System	Initial Capital (1000$)	Total NPC (1000$)	COE ($/kWh)	Fuel Consumption (Litter)
With TES	6350	14211	0.096	1 171 539
Without TES	6000	16009	0.105	1 448 524

This table shows that it is cost-effective to add a thermal energy storage system to the hybrid Wind-PV-diesel.

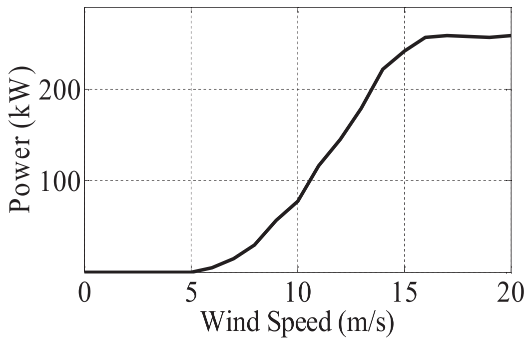

Fig. 6. Power curve of WES 30

B. Wind-PV-Battery

Hybrid system is implemented in HOMER software consisting of a WES-30 wind turbines and Torigan-T105 batteries. Some characteristics of this battery type is shown in table. 4, Fig. 7 and Fig.8.

TABLE IV
TECHNICAL CHARACTERISTICS OF TORIgAN-T105

Output voltage	6V
Normal capacity	225Ah
Lifetime	845kwh
Round trip efficiency	85%
Maximum charge current	11A
Minimum state of charge	30%

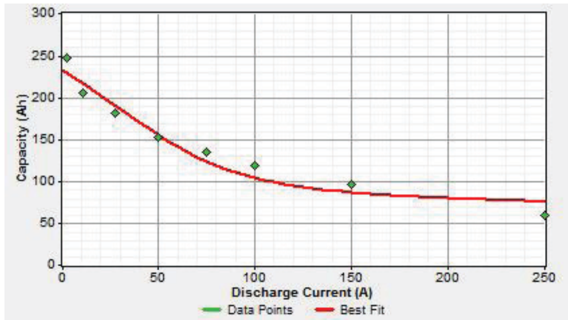

Fig. 7. Capacity curve of Torijan-105

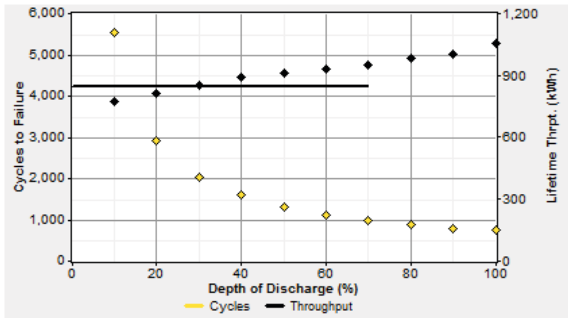

Fig. 8. Lifetime curve of Torijan-105

The most cost-effective combination of hybrid (wind-PV-Battery) system, in both with and without TES is compared in table 5. Also economic analysis of the proposed systems is listed in table 6. Based on table 3 and 4 it can be observed that usage of the TES not only causes decreasing of battery and converter capacity, but also causes decreasing the required capacity of PV system. The cost for producing 1kwh electric energy (COE) is decreased by 8.4%, whereas initial cost will increase by 5% due to TES investment costs.

TABLE v
PROPOSED COMBINATION FOR WIND-PV-BATTERY

Storage System	Wind Turbine WES 30	PV (KW)	Converter (KW)	Battery Torjan T-105
With TES	9	800	600	1400
Without TES	9	650	500	1100

TABLE VI
ECONOMICAL ANALYSIS FOR WIND-PV-BATTERY

Storage System	Initial Capital (1000$)	Total NPC (1000$)	COE ($/kWh)
With TES	10 212	12 738	0.083
Without TES	9 720	13 800	0.09

V. ENVIRONMENTAL ASPECT AND AIR POLUTION

One of the most important advantages of hybrid systems is decreasing the amount of the emission pollutants. Renewable resources have a great contribution in mitigating green house gases; however, the reliability of such systems is questionable. Therefore these systems should be equipped with backup systems or connected to the grid in order to compensate for the lack of generated power by renewable resources. For instance, wind speed and solar irradiation are not suitable complementaries for each for each other during 24 hours daily period. Fig. 9 shows that in night hours, both wind speed and solar irradiation are insufficient to meet the demand because the wind speed is less than V cut-in (5m/s for WES30) in most of the night hours. But diesel generator is a source of emission pollutants.

Different types of pollutants are produced during combustion of fossil fuels such as Carbon dioxide, Carbon monoxide, Particulate matter, unburned hydrocarbon, etc. these emission pollutants are damaging atmosphere and adversely affecting the human life by causing pollution to the local environment. The green house gases (GHG) emission per MWh energy production is given in Table 7 for diesel generator.

TABLE VII
GREEN HOUSE GASES EMISSION FACTOR OF DIESEL [7]

CO_2 (kg/Gj)	CH_4 (kg/Gj)	N_2O (kg/Gj)	GREEN HOUSE GASES (tCO2/MWh)
74.1	0.002	0.002	0.897

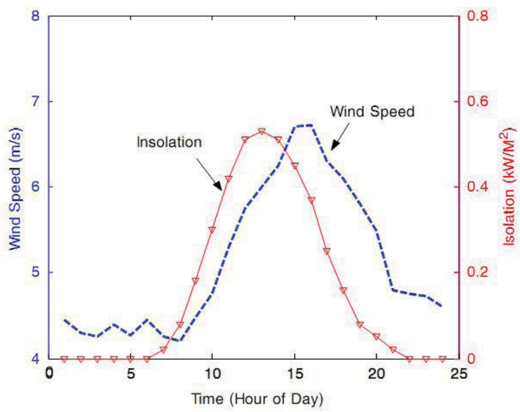

Fig. 9. Average hourly wind and insulation profile [8]

As listed in Table 3, TES system not only causes reduction of utilization and power supplying costs, but also it reduces the size of diesel generator, This improvement in size of diesel generator leads to a significant reduction of air pollution. Table 8 provides ratting reduction of some significant air pollution causes because of TES. Since the size of diesel generator decrease by 200kw, it causes fuel consumption decrease by 23%.

TABLE VIII
POLUTION GENERATED BY (WIND-PV-DIESEL)

Pollutant	With TES	Without TES
	Emission	(kg/year)
Carbon dioxide	3 085 048	3 814 440
Carbon monoxide	7 615	9 415
Unburned hydrocarbons	844	1 043
Particulate matter	575	710
Sulfur dioxide	6 195	7 660
Nitrogen oxides	67 949	84 014

VI. CONCLUSION

In order to improve reliability in hybrid system applications, batteries and diesel generators are usually used as back-up. High initial cost, high fuel cost and increasing air pollution causes, are some disadvantages of such back-up systems. In this paper, TES technique is employed for serving cooling loads in hot climate areas. The analysis of a PV-wind-diesel system is demonstrated by implementing TES technique, the amount of fuel consumption and consequently the air pollution will be decreased. The analysis of a PV-wind-battery system is also performed that indicates using TES causes decreasing of the size of the components of the mentioned hybrid system. Optimization results obtained from HOMER software have demonstrated, although using TES in hybrid systems leads to initial costs increase, the cost of electricity (COE-$/kWh) in a hybrid system equipped with TES is reduced by 8% compared with the conventional hybrid systems.

REFERENCES

[1] F. O. Hocaoglu, O .N.Gerek, M.Kurban "The effect of model generated solar radiation data usage in hybrid (wind–PV) sizing studies" Energy Conversion and Management, Volume 50, Issue 12, December 2009, Pages 2956-2963.

[2] O.Ekreb, B.Y.Ekren " Size optimization of a PV/wind hybrid energy conversion system with battery storage using simulated annealing" Applied Energy, Volume 87, Issue 2, February 2010, Pages 592-598.

[3] Application note " Thermal energy storage strategies for commercial and HVAC systems" pacific Gas and Electric company.

[4] G. Bekele, B. Palm "Feasibility study for a standalone solar-wind-based hybrid energy system for application in Ethiopia" Applied Energy, Volume 87, Issue 2, February 2010, Pages 487-495

[5] I. Dincer "On thermal energy storage and applications in building " Energy and Buildings, Volume 34, Issue 4, May 2002, Pages 377-388

[6] I. Dincer, M.A.Rosen, " Energetic, environmental and economic aspects of thermal energy storage systems for cooling capacity"

Applied Thermal Engineering, Volume 21, Issue 11, August 2001, Pages 1105-1117

[7] W.D.Kellogg, M.H.Nehrir, G.Venkataramanan, V .Gerez,”Unit sizing and cost analysis for stand alone wind,photovoltaic, a nd hybrid w ind-PV systems” I EEE T ransaction on energy conversion, 1998,13(1)

[8] D.B. Nelson, M.H. Nehrir, C. Wang “Unit sizing and cost analysis of stand-alone h ybrid wind/PV/fuel cell power generation systems” Renewable Energy, Volume 31, Issue 10, August 2006, Pages 1641-1656