A Proposed Strategy to Solve the Intermittency Problem in Renewable Energy Systems Using A Hybrid Energy Storage System

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Abstract: - Renewable energy resources are a favorable solution for the coming energy. So, a great interest has been paid in the last decades for developing and utilizing renewable energy resources as wind energy. As it has a large energy contents and, particularize with the availability, but the major problems of it are represented in unmatched with load demand because the intermittency and fluctuation of nature conditions. Many studies focused on the new strategy of using Battery Storage System (BSS), and solving some problems that affect the DC bus voltage and the BSS by using Electrochemical Double Layer Capacitor (EDLC). Their capability is to store energy to realize the objective of time shifting of surplus energy with a high efficiency. The article main objective is to model, simulate, design, and study the performance of a Stand-Alone Wind Energy System with Hybrid Energy Storage (SAWS-HES). Thus, a complete model of the proposed system is implemented including a detailed modeling procedure of the HESS components. In addition to the main contribution, a study of the performance of EDLC only as a storage device that has fast response device integrated to the suggested system then it hybridized with the BSS. The HESS has the capability to compensate the DC bus voltage in the transient conditions and gives good stability for the system. The SAWS-HES utilizes one main renewable energy resource as wind turbine and overall model is employed under MATLAB/Simulink including a developed simple logic controller. The SAWS-HES simulation results presented a promising performance and have a satisfied performance in meeting the end load demands at different operation conditions. This ensures the SAWS-HES reliability and the effectiveness with HES and the controller in stand-alone operation formulating an excellent solution for the renewable energy systems.

Key-Words: - Battery, EDLC, Hybrid energy storage, PMSG, Renewable energy, Wind turbine.

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1 Introduction

Wind energy is one of the important types of renewable energy as it is clean, inexhaustible and has low running cost [1-3]. Wind is created or generated due to the different temperature of the atmospheric layers because of the sun radiation effect, wind energy may be transformed to electric energy by using electric generators with a Wind Turbine (WT). This study exhibits the construction of the Wind Turbine based Permanent Magnet Synchronous Generator (WTPMSG), the working principles of it, the features of this type , the components of WTPMSG, voltage and current characteristics, the power flow, finally, the modeling, simulation of WTPMSG and the resulted curves of output power and operating voltage. PMSG is preferred instead of doubly feed induction generator because of its self-excitation capability, high efficiency operation [4] and do not need gearbox to match rotor speed and WT that mean lower faults, more reliability and less maintenance [5].

Now, the world is turning to renewable energy, instead of conventional methods of generating the electrical power that is a result of the environmental side effects of the use of conventional sources as the fossil fuels. One of the most important sources of it is the wind energy, and currently, the biggest challenge is to improve and develop the performance of wind energy systems to be better in application and economic terms. One of the greatest ways to improve wind systems is to use of energy storage systems to achieve an integrated, and more reliable and stable system [6 -7].

There are various Energy Storage Devices (ESDs), such as Battery Storage System (BSS), Electrochemical Double Layer Capacitor (EDLC) and Hybrid Energy Storage System (HESS) devices. HESS is considered the most widely used to avoid the known problems of renewable systems, such as intermittency and natural fluctuations, to meet the load demand without problems to become more stable and reliable system [8-9].

This paper is organized as follows. Section 2 presents the simplified electrical model of the wind power plant including the EDLC, BSS and HESS and its associated control strategy. Computational simulation and optimization of SAWS-HES using HOMER Pro software are presented in Section 3. Finally, Section 4 summarizes the simulation results of two different case studies, while Section 5 draws the conclusion.

2 System Description and Modeling

The configuration of the proposed wind power plant including the HESS is shown in Fig. 1. All component of power plant and the energy storage units are connected to a common DC bus through DC–DC converters. The common DC bus is connected to load through an inverter.

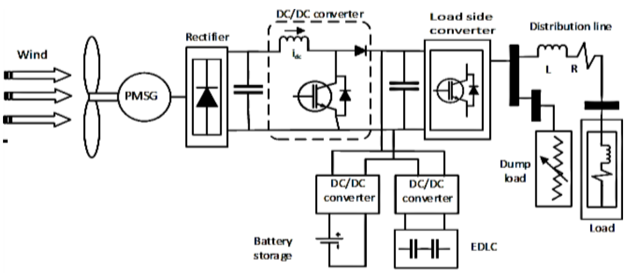

Fig. 1. The schematic diagram of SAWS-HES

2.1 Wind Turbine based Permanent Magnet Synchronous Generator

This part introduces an overview of WTPMSG that is shown in Fig. 2, the modeling and simulation of WTPMSG, the drive train and PMSG, the simulations with MATLAB/Simulink program have been performed. Wind turbine converts the power of wind to mechanical torque that calculated from mechanical power of turbine and the value of wind power depends on the wind speed and it can be calculated from the equations (1) to (5) [10-12].

$$P_{wt} = 0.5\,\rho \mathcal{A} \vartheta_{ws}^3 \quad (1)$$

$$P_m = P_{wt} C_{Pw}(\lambda,\beta);\; C_{Pw} < 1 \quad (2)$$

$$P_m = 0.5\,\rho \mathcal{A} \vartheta_{ws}^3 C_{Pw}(\lambda,\beta) \quad (3)$$

$$C_{Pw} = 0.22\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) EXP\left(-\frac{12.5}{\lambda}\right) \quad (4)$$

$$\frac{1}{\lambda_i} = \frac{1}{(\lambda + 0.08\beta)} - \frac{0.035}{(\beta^3+1)} \quad (5)$$

Where P_{wt} and P_m are the wind turbine power and mechanical output power in (W), respectively, ρ is the density of air in (kg/m^3), $\mathcal{A}$ is the swept area in (m^2), ϑ_{ws} is the speed of wind in (m/s) and C_{Pw} is the wind turbine coefficient of performance that calculated from function of the pitch angle of the blades (β) and the tip speed ratio(λ).

For the stabilization of small-scale wind energy conversion system studies, in this paper a Two Mass Drive Train (TMDT) model is utilized because the mass of turbine and the mass of generator are associated together by a shaft, the dynamic equations from (6) to (9) are describing the relation between the torques that produced by WT (T_m) and PMSG (T_g) [13].

$$T_m - T_{ss} = 2J_t \frac{d\omega_t}{dt} \quad (6)$$

$$\omega_t - \omega_{gen} = \frac{1}{\omega_{eb}} \frac{d\theta_t}{dt} \quad (7)$$

$$T_{ss} - T_g = 2J_g \frac{d\omega_{gen}}{dt} \quad (8)$$

$$T_{ss} = K_{ss}\theta_t + \zeta_t \frac{d\theta_t}{dt} \quad (9)$$

Where T_{ss} and T_g are the shaft and generator torques, respectively in (P.U.); ω_t and ω_{gen} are the turbine and generator speed ,respectively in (P.U.); ω_{eb} is the electrical base speed in (rad/s) ; J_t and J_g are the turbine and the generator inertias (s), respectively ; θ_t is the shaft twist angle in (rad), K_{ss} is shaft stiffness coefficient in (P.U./el.rad) and ζ_t is damping coefficient in (P.U.s/el.rad). The electrical model of PMSG of the system derived from q-d synchronous reference fame. Where, the d-axis is to be adjusted to the flux of the stator and the overall system can be illustrated according to equations from (10) to (12) [10-12].

$$\frac{1}{\omega_{eb}} \frac{d\Psi_{ds}}{dt} = \upsilon_{ds1} + R_s i_{ds} + \omega_{gen}\Psi_{qs} \quad (10)$$

$$\frac{1}{\omega_{eb}} \frac{d\Psi_{qs}}{dt} = \upsilon_{qs1} + R_s i_{qs} - \omega_{gen}\Psi_{ds} \quad (11)$$

Where

$$\Psi_{ds} = -\ell_{ds} i_{ds} - \Psi_m\,,\; \Psi_{qs} = -\ell_{qs} i_{qs} \quad (12)$$

Where υ_{ds1} and υ_{qs1} are the voltage of the generator components at direct and quadrature axis, respectively, R_s is the resistance of the stator, i_{ds} and i_{qs} are the current of the stator components at direct and quadrature axis, respectively, ω_{eb} the base angular speed in (rad/sec), ω_{gen} is the generator speed, Ψ_{ds} and Ψ_{qs} are the flux linkage components at direct and quadrature axis,

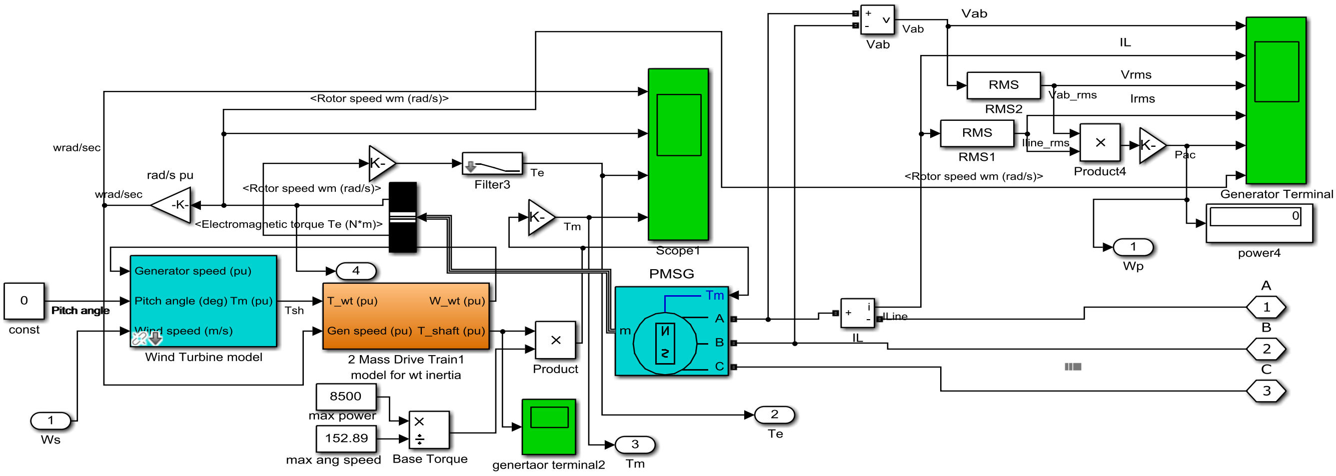

Fig. 2. The WTPMSG schematic diagram by MATLAB/Simulink

respectively and ℓ_{ds} and ℓ_{qs} are the stator leakage inductance components at the at direct and quadrature axis, respectively [14].

This part models the WTPMSG according to the previous mathematical equations of wind turbine, TMDT and PMSG, this system modeled in MATLAB/Simulink and the schematic diagram of the system is shown in Fig. 2, it consists of the WT, TMDT, 10 poles PMSG, and pitch angle control. The rated power of WTPMSG is 6 kW and the parameters of the system are from APPENDEX 1 [15].

2.2 Lead-Acid Battery Model

This type of batteries consists of lead metal as positive electrode and a negative electrode with a separator to isolate both electrodes. Sulfuric acid is utilized as electrolyte to give the sulfate ions for the responses of discharge. It is utilized for some applications as energy storage for power quality, Uninterruptible Power Supply (UPS) and intermittent renewable energy sources. However, short cycle life (500–1000cycles) [16] and low energy density (30– 50 Wh/kg) [16] are the problems of it. This type is with 20% Depth of Discharge (DoD) [17].

2.3 Electrochemical Double Layer Capacitors

EDLC is a good unconventional device to any applications that requires ESD because of many advantages as charge/discharge efficiency (90%-95%), long lifetime about 8-12 years, fast response, and wide operating temperature range because it can operate from -40ºC to 70ºC [18-19]. It is additionally concluded that EDLC technology is only useful within a limited range of energy and power needs. Outside of this limited range, the other options of energy storages systems appear to be great alternatives. Considering an EDLC of a capacitance C in Farads with initial voltage $\upsilon_{SC,i}$ in volts before discharge process and final $\upsilon_{SC,f}$ in volts after discharge process, the net electrical energy E_{SC} extracted or stored in the EDLC in Joule can be computed by Eq. (13).

$$E_{SC} = \frac{1}{2} C(\upsilon_{SC,i}^2 - \upsilon_{SC,f}^2) \quad (13)$$

As well known, an EDLC bank consists of a configuration of series and parallel capacitors called a bank to produce the desired rated terminal voltage and capacity. A simple model, as shown in Fig. 3, was suggested for a double- layer capacitor that includes a capacitance (C) with an Equivalent Series Resistance (ESR) and an Eequivalent Parallel Resistance (EPR) [20], where ESR is the equivalent series resistance in ohm(Ω) which represents the charging and discharging resistance and EPR is the equivalent parallel resistance in ohm (Ω) which represents the leakage or self-discharging losses occurring in the EDLC in case of long-term energy storage.

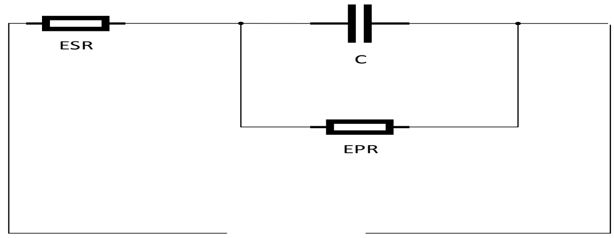

Fig. 3. The classical equivalent circuit of an EDLC [21]

For a bank EDLC, the total equivalent capacitance C_{total} and the total equivalent series resistance ESR_{total} can be calculated from Eq. (14) and Eq. (15), respectively, as follows [22]:

$$C_{total} = n_{sc,p} \frac{C}{n_{sc,s}} \quad (14)$$

$$ESR_{total} = n_{sc,s} \frac{ESR}{n_{sc,p}} \quad (15)$$

Where $n_{sc,p}$ and $n_{sc,s}$ are the number of parallel and series EDLCs in the bank, respectively.

3 Computational Simulation and Optimization of a SAWS-HES Using HOMER Pro Software

The proposed Stand-Alone Renewable WT System described in this part is supposed to be located at Al-Kosair, Egypt. A stand-alone power system in its general meaning can be defined as an autonomous micro-grid system that can provide electrical energy to load without connected to electrical grid. The proposed project is wind turbine connected to energy storage system. This system needs to get the optimal sizes of its main components, namely the wind turbine with BSS, EDLC or HESS to ensure its feasibility. That is can be done by a commonly used approach called HOMER optimization software as described in details in next section.

3.1 HOMER Pro Software

The optimal sizing and costing of the components of the proposed system can be done by utilizing HOMER (Hybrid Optimization of Multiple Energy Resources) pro software (version 3.13.6 [23]) which is developed by U.S. National Renewable Energy Laboratory (NREL). Simulation of HOMER pro can be done for grid connected the energy storage systems with different type of load profiles as shown in Fig. 4 [24-25].

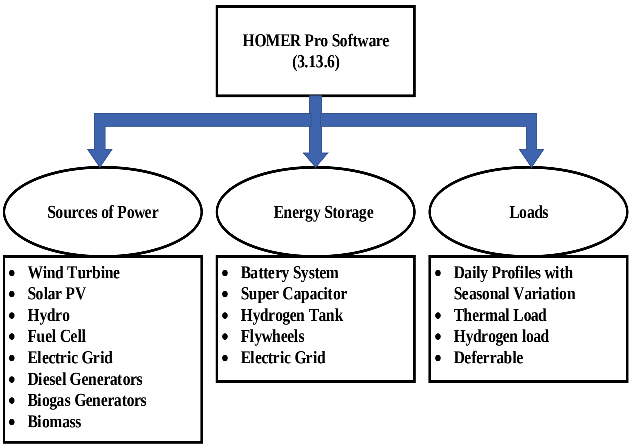

Fig. 4. HOMER pro components types

3.2 Area of Study and Its Resources

The proposed Stand-Alone Renewable Power System (described in this study is supposed to be located at Al-Kosair, Red sea governorate, Egypt which is located of 26º 6.1' N and 34º 15.8' E on the map that shown in Fig. 5. The selected area of study wind speed data is obtained from NASA surface meteorology database. Wind speed at 50m above the surface of the earth monthly average values over 10 years period is shown in Table 1.

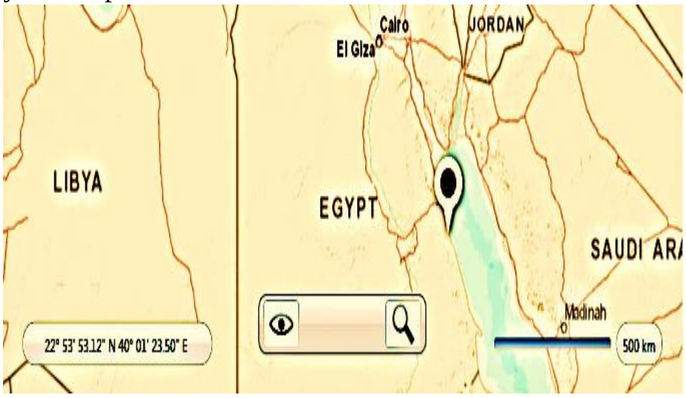

Fig. 5. The selected study area location in Al-Kosair, Red sea governorate, Egypt

Table 1. Monthly average wind speed data

Month	Average wind speed (m/s)
January	5.440
February	5.330
March	5.670
April	5.670
May	5.690
June	5.990
July	5.280
August	5.250
September	5.390
October	5.070
November	4.700
December	5.220
Annual average	5.390

3.3 Load Profile of this Study

The optimization process is done over one year period with a resolution of one minute as a time step. It takes in consideration the economic such as the maintenance-operation cost which taken as a percent of each component capital cost in the system, the inflation rate and discount rate are considered to be 2% and 5%, respectively. The simulated load profile was pre-developed in HOMER pro software. The profile has been scaled to the rating of 2 kW peak and daily consumption value is 11.27 kWh/d. The random day-to-day variability is considered to be 10% and the load variation over the full year period is shown in Fig. 6.

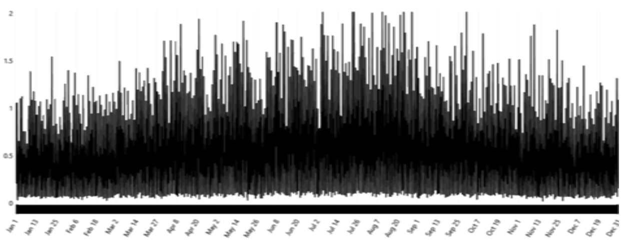

Fig. 6. The virtual load variation over the full year.

3.4 Parameters of Components and Units of the System

In the system structures, the load is connected to the AC bus. A WT power system and an energy storage unit are connected to the DC bus. the list of parameters for each component that utilized in the proposed system in the design, Sales prices for capital, replacement, operation and maintenance (O&M) costs of WT, battery, EDLC and converter [26-28] and the necessary parameters for simulation are shown in Table 2.

Table 2. Design parameters of components and units of system

component	Parameters Descriptions	
WT with rectifier	Rated capacity	6 kW
	Manufacturer	Bergey Wind power
	Model	Bergey Excel 6-R
	Capital cost	4500 US/kWh
	O&M cost/year	90 US/kWh
	Replacement cost	840 US/kWh
	Life time	25 years
BSS	Type	Lead acid
	Manufacturer	Generic
	Nominal voltage	12V
	Nominal capacity	1kWh
	Capital cost	300 US/kWh
	O&M cost/year	6 US/kWh
	Initial state of charge	100%
	Minimum state of charge	20%
EDLC	Manufacturer	Generic
	Nominal voltage	3V
	Energy stored	3.75Wh
	Rated capacitance	3000F
	Capital cost	20000 US/kWh
	Initial state of charge	100%
	Minimum state of charge	20%

3.5 Cost Optimization Methodology

HOMER optimization technique depends on the cost of each singular component of the system under study. HOMER simulates each system configuration to reach to the best system size and the lowest price. Here, the total cost C_S to be optimized is a function of the cost of each individual component, definitely the cost of wind turbine C_{WT} , the energy storage system C_{ESS} , the Converter C_{conv} , all of those are formulated in equation (16) as follows [29-30].

$$C_s = C_{WT} + C_{ESS} + C_{conv} \quad (16)$$

The cost of above components be determined by its initial and running cost and it can be calculated by equation (17).

$$C_j = N_j * \left[\mathrm{Cap.}C_j + \left(\mathrm{Rep.}C_j \times NR_j\right) + OMC_j\right] \quad (17)$$

where j refers to an individual component of the System, N_j refers to the number or size of the component, $\mathrm{Cap.}C_j$ represents the capital cost component, $\mathrm{ReP.}C_j$ represents the replacement cost of the component, NR_j is the number of replacements of the component and OMC_j represents the operation and maintenance cost of the component. The capital cost components, replacement and maintenance cost values, those were considered and utilized in the process of the sizing optimization are listed in Table 2 [24, 31].

3.6 HOMER Results

HOMER optimization process for the WT and energy storage system has been performed according the aforementioned configuration with the above-mentioned load profile. The overall results of HOMER Pro simulation model with a 6 kW rated capacity WT system are presented in Table 3, cost optimization results of a 6 kW rated capacity WT in case of using BSS only and in case of using EDLC only are presented in Tables 4 and 5 respectively. The Net Present Cost (NPC) of the WT system with BSS is 53,275 $ for a life time of 25 years and its energy losses are about 6% from total consumption. NPC of the same system but with EDLC is 721,239 $ for the same lifetime and its energy losses are about 4.2% , it is noted here the NPC in the case of the system with EDLC is about 14 times of the NPC in the case of the system with BSS but it reduced the energy losses about 1.8%.

The electrical power generated by WT is used to feed the AC primary load. The average consumption of the AC primary load is 4112 kWh/year. The monthly average electricity production of the WT system is shown in Fig. 7; it shows the goodness of the wind potential of the suggested location over the full year period, which confirms a good yield of wind energy production. The optimal size of BSS is 40 batteries of 1kWh (Lead acid battery) and the State of Charge (SoC) of BSS and also from the

HOMER optimization results the optimal size of EDLC for the same conditions is 9120 cells of 3000F EDLC ,3.75Wh per cell.

Table 3. Optimization results for the system

Production Summary	
Bergey Excel 6-R(WT)(kWh/yr)	13,410
Consumption Summary	
AC Primary Load (kWh/yr)	4112
Result Data in case of using BSS	
Energy Out percentage from total consumption	24%
Losses percentage from consumption	6%
Result Data in case of using EDLC	
Energy Out percentage from total consumption	24%
Losses percentage from consumption	4.2%

Table 4. Optimization results for WT with BSS

Architecture			Cost			
WT	BSS	Converter (kW)	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
1	40	2.08	53,275	0.739	780.00	39,603

Table 5. Optimization results for WT with EDLC

Architecture			Cost			
WT	EDLC	Converter (kW)	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
1	9120	2.04	721,239	10.01	540.00	711,774

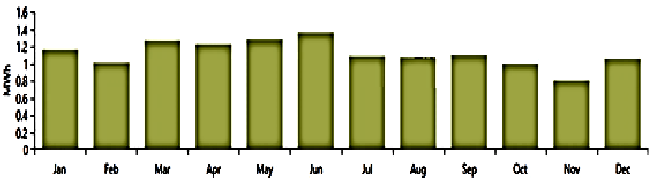

Fig. 7. The monthly power production of the WT system

4 The SAWS-HES Simulation Results and Discussion

The SAWS-HES simulation is achieved under MATLAB/ Simulink version: 9.1.0.441655 (R2016b) Simulink that is running on an Intel ® core ™ i3-3217U CPU, 1.8 GHz, 8 GB RAM Laptop. Even so, the dynamic model in the simulation needs a long time for its stiff structure of the model and the included complex and non-linear systems of the parts of the whole system. The SAWS-HES main partition of its control scheme is built to keep the DC bus voltage constant within suitable limits because the DC bus is the backbone of the proposed system. The system components such as the WT and HES are operating at different voltage levels and types. Therefore, its output voltages must be controlled and adapted to the range of the 120v DC voltage to be provide the DC bus. Then the DC voltage is fed a DC load or connected to an inverter providing the AC load.

In the event of shortages in the renewable source there is a need for the energy storage system. So, the storage system compensates the difference between the demand of load and the generated power. The energy storage system components are operating at different voltage levels rather than the DC bus voltage. Thus, there is need for utilizing conditioning circuits to link the above stated components of DC bus. Conditioning circuits regulate the voltages from or to the DC bus and they are playing a vital role in applying the power control of the SAWS-HES.

4.1 The SAWS-HES Simulation with BSS Only

The first case of the SAWS-HES simulation with BSS only had to be run for 10s with a condition of the wind turbine operating at wind speed of 12 m/s. The WTPMSG produces more than enough power higher than the load demand previously set at 5 kW and the BSS SoC is about 44.5%. The system simulation process reaches the steady state at time less than 1 sec. A scheduled increase in the end load demand of 5 kW to 10 kW had been made to check the system effectiveness and stability of the controller and the conditioning circuits. The system keeps the DC bus voltage at preferred limits to ensure the system reliability to feed the end load demand with a high quality of delivered voltage.
The end load power demand curve is depicted in Fig. 8. The corresponding renewable extra output power that exceeds the end load power demand is fluctuating from 5 kW to 10 kW at the time of 4 sec. Which is enough to operate the BSS to discharge. In Fig. 9 which describes the state of the BSS current which matching with power fluctuations to compensate the drops, and in Fig. 10 which describes the state of the DC bus voltage and there is a small negligible drop in voltage from 115v to 109v for 3 seconds that ensuring the quality of the strategy in providing a stable DC bus voltage and good quality of delivered power to end load. Figures 8 to 10 describe the status of the BSS conditions and the DC bus voltage stability and notches that are reached to 75v and

123v due to the rising of load and reducing it respectively when utilize BSS only.

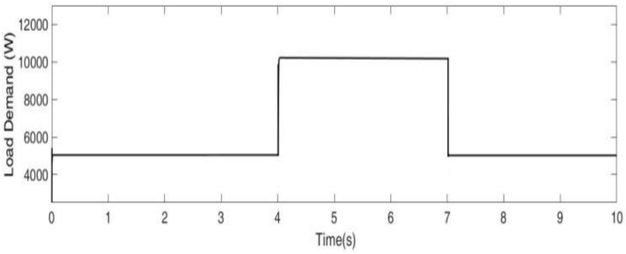

Fig. 8. The end load power demand

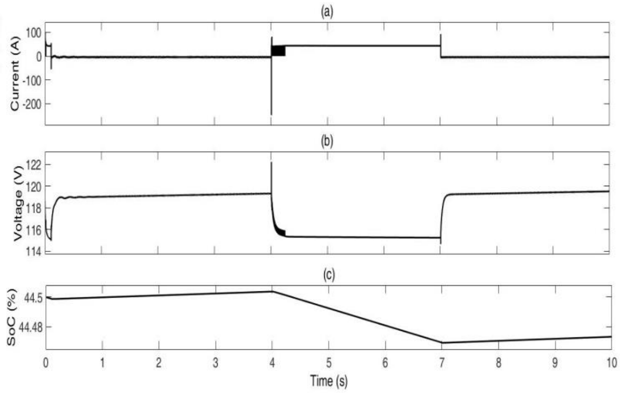

Fig. 9. Battery (a)current, (b)voltage and(c) SoC versus time

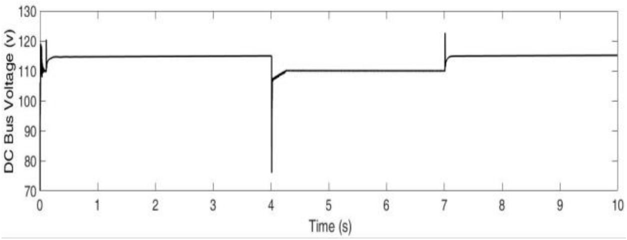

Fig. 10. The DC bus voltage with BSS only

The previous displayed simulation results show the behavior of the system in case of using BSS only, For this case the BSS gets steady state Hardly in a split second at the time of 4s when the load raised suddenly as shown in Fig. 9 and also, DC bus voltage reaches to steady state with settling time that can be shown in Fig. 10 at times 4s and 7s, from the previous results there are some problems appeared when using BSS only as an energy storage that may be effects on the sensitive and important loads.

4.2 The SAWS-HES Simulation with BSS and EDLC

In this case of the SAWS-HES simulation with both the BSS and the ELDC, which is HESS had to be run for 10s is performed at a condition that the WTPMSG with wind speed about 12 m/s. The load demand power is presented in Fig. 8 and the state of charge of the EDLC and the BSS are considered in this simulation 54.3% and 44.5 %, respectively. At the time of 4s an extraordinary transient increase in load demand by 5 kW had been made and the total load demand to 10 kW. As a result, the system succeeded to adjust its operating point and share the increase between the WT system and the HESS as depicted in Figures 11 and 12. Finally, the resultant effects on the DC bus voltage are shown in Fig. 13, there is a very small negligible drop in voltage from 118v to 116v. Those Figures show a fast restoration and reasonable performance of the steady state condition. The system returns to its steady state values after rising the load demands successfully, which emphasis the robustness of the operational control strategy against the sudden changes in tracking the load demand.

Figures 11 to 13 describe the status of the HESS devices conditions and the DC bus voltage stability and notches that are reached to 95v and 144v due to the rising of load and reducing it, respectively.

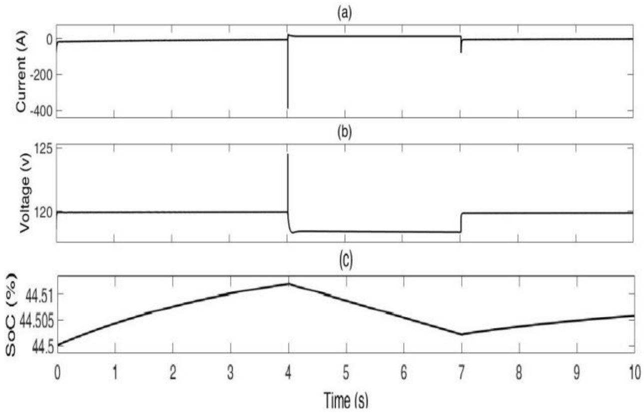

Fig.11: Battery (a) current, (b) voltage and(c) SoC versus time

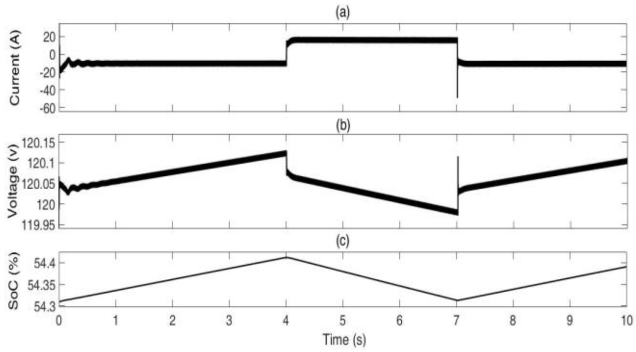

Fig.12: EDLC (a)current, (b)voltage and(c) SoC versus time

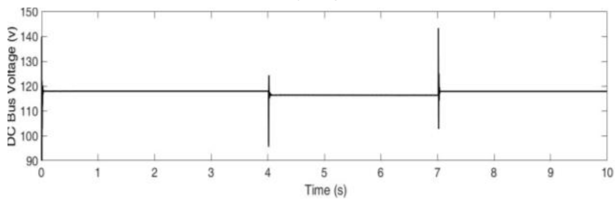

Fig.13: The DC bus voltage with EDLC and BSS

The notches of DC bus voltage with HESS are less than the resulted notches when using the BSS only. When raising the demand load, it is observed that the discharge rate of the battery is lower in this case, because the EDLC shares it in the load current, which means fewer charge cycles, longer battery life, lower maintenance. In addition, the problem that appeared on the BSS at the time of 4s at the first case is solved by using HESS.

4.3 The SAWS-HES Simulation with EDLC Only

The third case of the SAWS-HESS model simulation with EDLC only is to be run for 10 seconds of operation with stable conditions. The wind speed is 12 m/s as the input of the WT. The system is directed to feed demand load for the case that suggested herein, the demand load is fixed at 5 kW for 4 seconds then raised instantaneously to 10 kW for 3 seconds. Finally, demand load will remain constant at 5kW for the last 3 seconds of operation. Wherever the EDLC SoC was 54.3% of its capacity and the rated output power of WTPMSG is 6 kW.

The resulted output power curves of the load demand, shown in Fig. 8, difference between the WT output power and the end demand of load can be called an extra power. This extra power firstly is directed to the ELDC to store this extra to be utilized at shortages times as shown in the same Figure, when the demand load rose to 10 kW at time of 4sec the EDLC discharged to feed the shortage, then at the time of 7sec the load demand changes to 5 kW. The EDLC current, voltage and SoC versus time are shown in Fig. 14 and finally, the Fig. 15 which describes the state of the DC bus voltage with a small negligible drop from 120v to 119.6 v about the time of 3 s due to the load increase. That is noted that the DC bus voltage is very smooth and there are no notches when the load raised and reduced respectively.

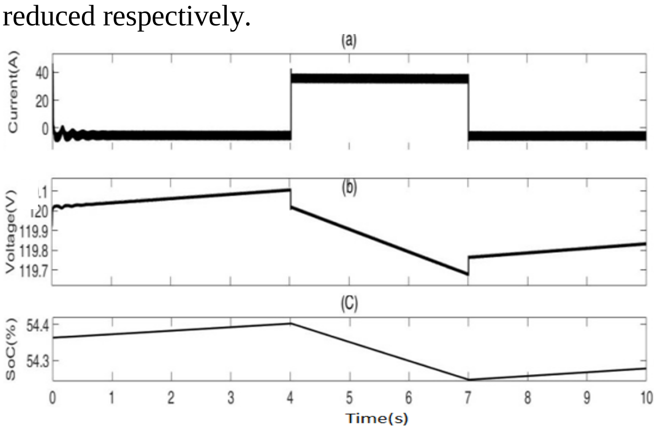

Fig.14: EDLC (a)current, (b)voltage and(c) SoC

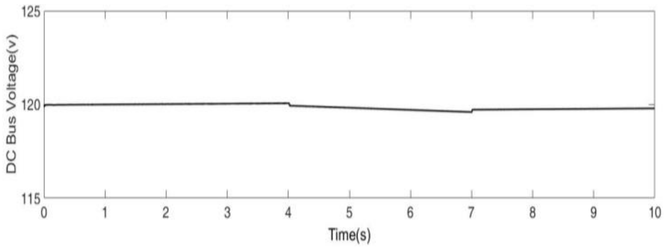

Fig.15: The DC bus voltage by utilize EDLC only

Although EDLC is much more expensive than batteries, it is very important in the event of loads of high sensitivity. From the previous optimization results that show that the cost of operating a system that works based on EDLC only may cost about 14 times the cost of the system that works based on BSS, and for this, it is necessary to determine the ratio from each system commensurate with the requirements of the load. So, assume that there are important and sensitive loads at a rate of about 20% of the total loads ,so HESS can be utilized by using 20% of EDLC system that costs about 144,247$ and 80% of BSS which is its cost is 42,620$ and the total cost of the HESS is 186,867$.

5 CONCLUSIONS

The importance of SAWS-HES accurate modeling in simulating the real device performance, the system of second case has the advantage of hybridization of storage devices that made the system more reliable and stable, the goodness of utilizing HESS and its active role in satisfying load demands at shortages.

According to simulation the system succeeded in load demand satisfaction and keeping the DC bus voltage at its desired limits in favor of the logic controller, conditioning circuits in the three cases of utilizing EDLC only, BSS only and utilizing HESS.

From the results of the previous cases, it is concluded that DC voltage stability in the second case when utilizing HESS is the best because it is lower variation of voltage from the first case (118v to 116v) and lower cost from third case. Utilizing HESS in the second case is better than the first case because it has the lower notch in DC voltage when the load is raised suddenly.

Utilizing HESS is the best if there are sensitive loads or important loads because of its reasonable cost. It also improves the battery performance because EDLC shares the load current with BSS that mean longer life, fewer charge and discharge cycles and lower maintenance, and the problem that appeared on the BSS at the time of 4s at the first case is solved by using HESS.

Using of HESS for renewable source is more stable than using BSS only because the EDLC to cover “high power” demand, transients and the fluctuations that resulted from fast load and consequently is characterized by a fast response time, the cost of using HESS also is186,867$ so its cost is lower than using EDLC only.

From the results of utilizing BSS only, HESS and EDLC only with the simulation of the system, HESS operated with better performance with reasonable cost than both BSS only and EDLC only.

Finally, Using EDLC only is the best DC voltage in performance, stability, efficiency, and smoothing, but it is the most expensive. So, in the case of using HESS, DC bus voltage found to exhibit remarkably improved performance, more smooth, lower voltage drop and lower notches in DC bus voltage when rising the demand load suddenly from using BSS only and its cost is reasonable.

The scope of this paper was associated with studying, modeling, designing and analyzing a stand-alone renewable system utilizing the WT based on the HESS. In future works it is planned to organize a larger scale renewable system utilizing a hybrid of the WT and PV system based on the HESS connected to grid utility to study the interactions between them and utilize and integrate a fuel cell with the system. It is planned also to develop an advanced control strategy to cover all expected scenarios. Those ensure the suitable interconnection and get the maximum benefit from integrating renewable with fuel cell and Energy storage systems into grid. In addition, it is planned to work on optimization of the whole system in order to develop a more efficient adaptive controller for power applications and automotive systems.

APPENDIX 1

Two mass drive train parameters

J_t (s)	4
J_g(s)	0.4
K_{ss}(P.U./el.rad)	0.3
ζ_t(P.U.s/el.rad)	0.7

PMSG Ratings and parameters

Rated speed (rad/s)	153
Rated power (kW)	6
Rated torque (Nm)	40
Magnetic flux linkage (Wb)	0.433
No. of poles	10
Resistance of stator [R_s] (Ω)	0.425
Inductance of stator [ℓ_s] (mH)	8.4

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