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Increasing the Battery Life of the PMSG Wind Turbine by Improving Performance of the Hybrid Energy Storage System

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Abstract: *Nowadays, with an increase in the number of wind power plants, the rules for connecting these plants to the grid have been changed. Under the new standards, to maintain a frequency stability, the power variations of wind farms must be limited. For this reason, the use of the energy storage sources along with wind turbines have been proposed and many publications have been published on this subject. One of the energy storage systems is the hybrid energy storage system with battery and capacitor. In this paper, the control of the hybrid energy storage system with battery and capacitor for the PMSG based wind turbines has been investigated and a method is proposed to control and divide the power between the battery and the capacitor. By eliminating the unnecessary charges and discharges of the battery, which existed in the conventional approaches, this method improves the performance of the energy storage system and increases the battery life compared to the conventional methods. Finally, the functionality of the proposed method is investigated by simulation in MATLAB/simulink software.*
Keywords: *Battery lifetime; Hybrid energy storage system; Output Power smoothing; Permanent magnet synchronous generator; Windturbine.*

I. Introduction

The increasing growth of the world population and industrialization in developing countries have increased the use of the fossil fuels. Excessive consumption of the fossil fuels results in a reduction in the reservoirs and an increase in air pollution and the price of fuels. Thus, considering the problems of fossil fuels and the increasing global need for energy, the use of renewable energy sources has been taken into consideration more and more. Among renewable energy sources, wind energy has been considered very largely due to its high production capacity up to several megawatts as well as its fast return on the investment. Today, most distributed generation power plants which use wind energy produce a small portion of the total power that is injected into the power system. In this case, network variations affect the turbine, however, the turbine has no significant effect on the grid stability because the variations in a small portion of the grid"s power doesn"t affect the grid frequency. Due to the growing use of the wind turbines in the world, this will change soon and as a result, the grid frequency will be affected by the wind turbines. Hence, if the injected power of these turbines changes a lot, the grid frequency will change. These variations will result in the power system instability. In order to avoid grid instability, a limit is imposed on the output power of these sources. The amount of this limit is different in various countries and depends on the wind turbine production capacity in each system.

In this paper, a method is proposed in which the power reference of the battery and the capacitor is determined without the use of any optimization algorithm. Therefore, some of the problems of the optimization methods such as response divergence and long response time don"t exist in this method. An electric battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. Each cell contains a positive terminal, or cathode, and a negative terminal, or anode. Electrolytes allow ions to move between the electrodes and terminals, which allows current to flow out of the battery to perform work. Rechargeable batteries can be discharged and recharged multiple times and the original composition of the electrodes can be restored through reverse current.

Rechargeable batteries are used for automobile starters, portable consumer devices, light vehicles (such as motorized wheelchairs, golf carts,electric bicycles, and electric forklifts), tools, and uninterruptible power supplies. Grid energy storage applications use rechargeable batteries for load leveling, where they store electric energy for use during peak load periods, and for renewable energy uses, such as storing power generated from photovoltaic arrays during the day to be used at night. By charging batteries during periods of low demand and injecting energy to the grid during periods of high electrical demand, load-leveling helps eliminate the need for expensive peaking power plants and helps reduce the cost of generator operations. Current Li-Ion batteries offer an energy density of about 160 Wh/kg.

Indentations
Moreover, in this method, power division is done according to the state of the system while in power division via filters, taken into account.
The rest of this paper is as follows: section 2 presents a general overview of the system. The proposed control algorithm is presented in section 3. To evaluate the performance of the proposed method some simulation has been done using Matlab/Simulink. Section 4 is assigned to the simulation result. Finally section 5 concludes the paper.

II. System's Model

Fig. 1 shows a simplified block diagram of a wind turbine equipped with a permanent magnet generator and a hybrid energy storage system. Wind turbine absorbs the power from the wind according to the wind speed and the rotational speed of the turbine and delivers this power to the DC bus. The system can be divided into 2 parts. The mechanical and the electrical part. In the following, the operation of each part has been explained.

A. The Mechanical Part

The task of the mechanical part is to absorb power from the wind and deliver it to the generator shaft.
Black lines: The turbine‟s input power against turbine speed for different wind velocities
Brown line: The turbine‟s output power against turbine speed be seen in this figure, at any wind speed, the maximum power that can be
Absorbed from the wind is achieved at a particular rotational speed called the maximum power point.
At nominal wind speed and maximum power point, the turbine absorbs nominal power. When the wind speed increases and becomes greater than the rated wind speed, at maximum power point, the power that is absorbed by the turbine will become greater than its rated power. Hence, if the turbine is planned to operate at wind speeds greater than the rated speed, it shouldn‟t be at the maximum power point. Thus at wind speeds greater than the nominal value, turbine rotates at a speed to absorb the rated power [3].
In Fig. 2, the output power variation curve is shown in terms of different wind speeds (Brown line). As can be seen, when the wind speed is less than the nominal value, the power that is produced by the turbine is at its maximum possible amount. When the wind speed becomes higher than the rated value, the nominal power is absorbed from the wind. The turbine output power curve .

B. The Electrical Part

The 1st part of the electrical system is the generator. The generator used in the system presented in Fig. 1 is a permanent magnetB-1. *Control of the Generator-side Converter*

The task of the generator-side converter is to deliver the power of the generator to the DC bus and adjust the turbine speed. In this regard, first, the reference is determined. If the wind speed is less than the rated value, the generator‟s speed reference will be determined by the maximum power point tracker (MPPT). Otherwise, the speed reference will be calculated in a way that the turbine absorbs the nominal power. Then, the generator speed is compared to the speed reference. In case the generator speed were less than the speed reference, the q axis current of the generator would decrease. The result is a reduction in electrical torque and eventually an increase in generator speed. In case the turbine speed were higher than the speed in maximum power point, the operation would be the same. The task of the generator-side converter is to absorb this current reference from the generator and deliver the produced power to the DC bus. Fig .3 shows the control algorithm of the mentioned method.

B-2. *CONTROL OF THE GRID-SIDE CONVERTER*

The task of this converter is to deliver the power from the DC bus to the grid. This transmission must be in such a way that meet the grid standards. Also, the voltage of the DC bus must be controlled if possible. Furthermore, this converter has to control the output voltage by controlling the reactive power that is injected into the grid.

B-3. *Control of the Energy Storage System*

The generator-side and the grid-side converters are separated by the DC link capacitor. If there were a difference between the input and the output power of the DC link, this difference would lead to charges and discharges of the DC link capacitor and thus variations in its voltage. Hence, a system must adjust the voltage of the DC link at the nominal value. For this purpose, two DC to DC converters are used. One side of these converters is connected to the DC bus and the other side is connected to the battery and the capacitor. In this case, the DC bus voltage is compared to a reference voltage and the difference passes through a PI controller. The output of the PI controller is the power reference of the energy storage system.

Finally, this power must be divided between the battery and the capacitor. In order to determine the battery and the capacitor power references, a low pass filter is used to separate the low and high frequency fluctuations.
In order to prevent the capacitor from over charges and over discharges, a proportional controller is used. The output of this controller produces a current reference which is added to the current reference of the battery by a feed-forward.

The proper charge of the capacitor is considered to be in the middle of the allowed operating zone in order to allow the capacitor to absorb the power fluctuations with the lowest frequency and also to inject these fluctuations into the grid. In this case, if the capacitor state of charge (SOC) were higher than this proper charge, a current would be injected to the battery and if the capacitor‟s voltage were lower than this amount, a current would be drawn from the battery to bring the capacitor‟s voltage closer to the ideal value. The amount of this current is proportional to the difference between the capacitor SOC and the determined charge.

This problem also exists for the battery. The battery may also experience over charge or over discharge conditions. To solve this problem, in case of a low battery state of charge, the output power is reduced so that a share of the produced power charges the battery. In case the battery state of charge were high, the output power would increase (considering the allowed limits) to deliver a share of the battery‟s stored energy to the grid.
In this control method when the power is divided by a low pass filter, it can be seen often that although the capacitor has a high state of charge, the battery injecting power into the grid or while the capacitor has a low state of charge, both the battery and the capacitor absorb power according to the difference between the output power and the power produced by the turbine. However, after providing the required power by the energy storage system, a current is injected or drawn from the battery to bring the capacitor state of charge closer to its ideal value. The unnecessary charging and discharging of the battery, reduces the system‟s lifetime. If the adjustment of the voltage of the capacitor bank to the ideal value is done by the input power, then the battery life will increase. In the following, a method is proposed for dividing the power between the battery and the capacitor to minimize the problems that are mentioned above and to increase the battery life compared to the conventional methods .

III. The Proposed Method

In this method, first, the charging and discharging conditions of the energy storage system and the voltage of the capacitor are investigated. If the energy storage system were being charged and the capacitor‟s SOC were less than 50%, the capacitor would receive the power alone until its SOC reaches 50%. If the capacitor‟s SOC were higher than 50% and the capacitor were absorbing the power alone, it would become fully charged quickly. After being fully charged, all of the power would be provided by the battery. Therefore, when the capacitor is in this area, the power is divided between the battery and the capacitor by a low pass filter. When the capacitor‟s SOC is more than 50% and the system is injecting power into the grid, the power will be supplied through the capacitor until the SOC reaches 50%. With this, not only the time that was required by the battery to supply power is reduced but also it takes less time that the capacitor‟s energy reaches its reference amount. When the capacitor‟s SOC reaches 50% and the power division changes from the capacitor alone to the conventional method or vice versa, there will be rapid changes in the battery current (since the battery‟s power reference changes as stairs). Therefore, to avoid these rapid changes, a low pass filter is used with a frequency of 10 times as much as the cur-off frequency of the power division system. This value is chosen so that the 2nd filter has no impact on the power division. In general, according to the state of charge of the energy storage system and the voltage of the capacitor, the following operation areas can be considered for the system. **The capacitor SOC is greater than its ideal value and the current is positive:** In this case, the voltage of the capacitor is high and the system is absorbing power. In this area, the capacitor operates like the conventional method and considering the amount of the energy that the capacitor can store, the power division between the battery and the capacitor is performed.
x **The capacitor SOC is less than its ideal value and the current is negative:** In this case, the voltage of the capacitor is low and the system must inject power into the grid. In this area, the capacitor operates like the conventional method and considering the amount of power that the capacitor can supply to the grid, the power half. Once the capacitor state of charge reaches 50%, the system state changes and the power is divided between the battery and the capacitor.
x **The capacitor's SOC is greater than its ideal value and the current of the energy storage system is negative:** In this case, the capacitor state of charge is higher than 50% and the system is being discharged. In conventional methods, both of the systems are discharged first. After a change in the current‟s polarity, the battery charges so that the capacitor reaches its ideal point. In this method, when this happens, all of the current is drawn from the capacitor. This continues until either the current‟s polarity changes or the capacitor‟s SOC becomes less than 50%. In this case, the battery‟s power changes from zero to a new value which is determined by the filter.

The figure below shows the control algorithm of the proposed method. As can be seen, first, the power of the Hybrid energy storage system passes through a low pass filter. In the conventional method, the output of the filter determines the battery power. On the other hand, it is examined whether the power of the energy storage system is positive or negative. Also, the capacitor state of charge is investigated. If the capacitor SOC were low and the power of the energy storage system were positive, X would become zero. Another case where X becomes zero is when the voltage of the capacitor is high and the power of the energy storage system is negative. In other cases, X equals to 1. This amount is multiplied by the power reference which is calculated by the filter. As a result, the power of the battery will become zero, if the capacitor‟s voltage is high and the power of the energy storage system is negative. Also, this will be valid in case the capacitor‟s voltage is low and the power of the energy storage system is positive. The result of the X times the output of the LPF1 passes through another low pass filter (LPF2) with a cut-off frequency 10 times as much as the cut-off frequency of the first filter. So, the rapid changes of the battery power during this filter is considered to be high, it doesn‟t have any impact on the power division. Another point that must be noted is that because of the new proposed control method, the proportional the variations of X is overcome. Since the cut-off frequency of controller cannot be omitted since the proportional controller is applicable to all cases. However, the new controller is applied when a specific condition prevails over the system.
division between the battery and the capacitor is performed.

x **The capacitor SOC is less than its ideal value and the current of the energy storage system is positive:** In this case, the capacitor is partially charged and the energy storage system is being charged. First, the current reference of the battery is set to zero in order to avoid the battery and the capacitor to charge simultaneously and then the battery discharges into the capacitor and hence prevents a reduction in the battery life. This is done as long as the capacitor state of charge is located in its lowerhalf. Once the capacitor state of charge reaches 50%, the system state changes and the power is divided between the battery and the capacitor.

x **The capacitor's SOC is greater than its ideal value and the current of the energy storage system is negative:** In this case, the capacitor state of charge is higher than 50% and the system is being discharged. In conventional methods, both of the systems are discharged first. After a change in the current‟s polarity, the battery charges so that the capacitor reaches its ideal point. In this method, when this happens, all of the current is drawn from the capacitor. This continues until either the current‟s polarity changes or the capacitor‟s SOC becomes less than 50%. In this case, the battery‟s power changes from zero to a new value which is determined by the filter.

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FIGURE

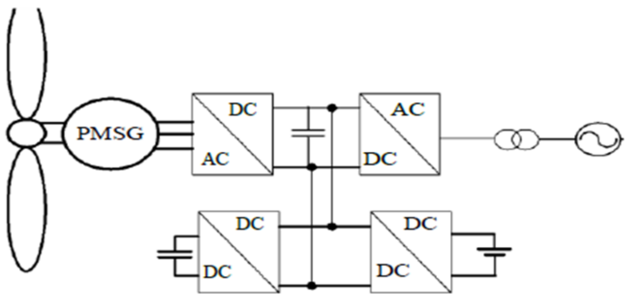


Fig 1. Overall structure of the system

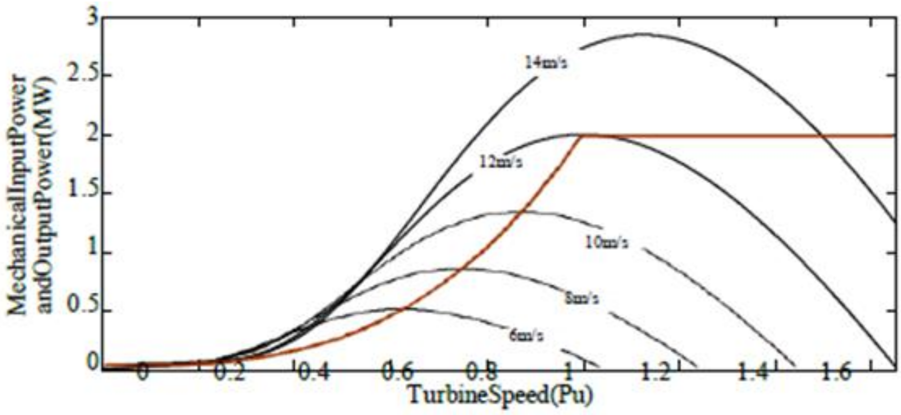
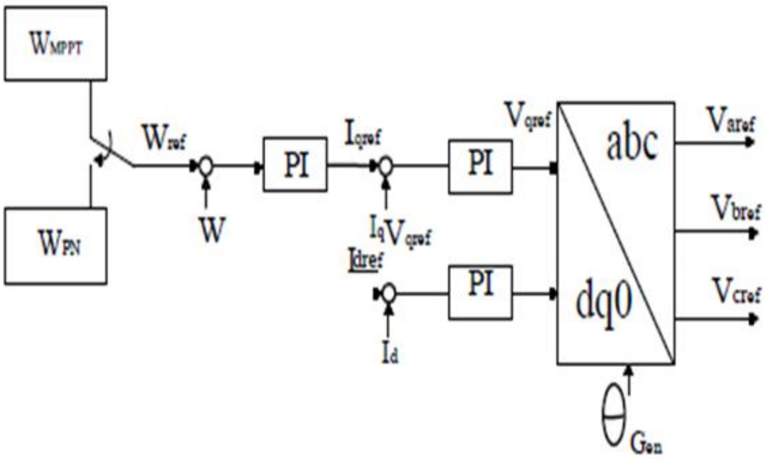


Fig 2. Black lines: the turbines input power against turbine speed for different Wind velocities



Brown lines: The turbines output power against turbine speed

Fig 3. Control system of PMSG

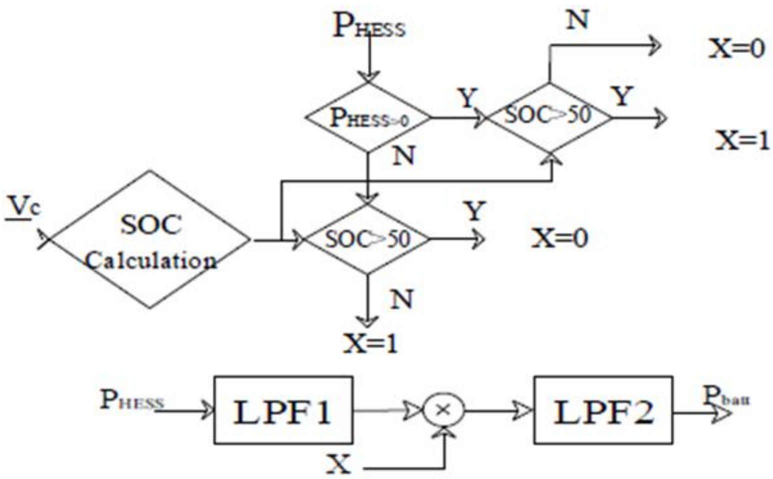


Fig 4. Proposed method approach schematic

IV. Conclusion

In this paper, the output power smoothing of the PMSG based wind turbine was studied by means of a hybrid energy storage system. For this purpose, different parts of the PMSG wind turbine along with its control system was described. After that, considering the goal of this paper, the problems of the conventional energy storage systems with battery and capacitor were described. It was observed that in the conventional method ,At intervals the battery experienced unnecessary charges and discharges which is the long run reduces the battery life .The main goal of the proposed method was to distribute the power between the battery and capacitor such that unnecessary charge and discharge of the battery was reduce which resulted in longer battery life time.

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