Novel Energy Management System of PMSG based Standalone Wind Power Generation System

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Abstract: Renewable energy sources based electric power generating units are often power supply units for many rural areas worldwide especially where power supply is impossible through the power grid. Permanent Magnet Synchronous Generation (PMSG) based wind power conversion system is considered in this paper and equipped with an efficient maximum power tracker (MPPT) circuit. However, electricity produced through wind turbine will be always fluctuating according to wind speed. Hence, an energy storage device (i.e., batteries) is also connected through a dc to dc bidirectional circuit. Moreover, during light load conditions, a dump load also incorporated to consume excess power in case batteries are fully charged. A common dc-link is established by connecting MPPT circuit of wind system, bidirectional converter and dump load along with a power electronic switch. Novel control methods are proposed to all converters to maintain constant voltage at dc-link under various changes happened in the standalone system. In order to provide supply to AC loads, an inverter with voltage control unit also connected between load bus and dc-link. An efferent energy management algorithm is developed based on controlling the voltage at dc-link. MATLAB/Simulink is used to analyze the standalone power supply system and applied various operating conditions to present results.

Keywords- Standalone power supply system, wind power conversion, PMSG, power quality, energy management system.

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1. INTRODUCTION

Still there are some remote areas worldwide where only diesel generators are used for supplying electricity to loads. Majority of such places are located on hills. Only wind energy can be easy to produce electricity with low cost as compared with other options in such locations. Using renewable energy for electric power generation can be able to reduce pollution also. Hence, establishing a standalone power supply system through wind turbine energy conversion system will be a feasible solution for solving many problems. Generally an electrical generator must be required for power generation through wind turbine system. Apart from many, Permanent Magnet Synchronous Generator (PMSG) is commonly used for medium power generation system from range few kW to 10 MW. Therefore, PMSG interfaced standalone wind power conversion system is considered in this paper as power source. However, power generated through wind system always fluctuates according to changes in wind speed. Therefore, a battery storage system must be connected to manage energy balance between total production and operating load under variations in the standalone system.

Best utilization of wind turbine power conversion system can be achieved by interfacing an efficient Maximum Power Point Tracking (MPPT) device in between dc-link and wind power unit. Usually, PMSG produces three phase output, hence a diode rectifier in used and a boost converter is placed in between dc-link and diode rectifier to work as a MPPT circuit. Once battery is fully charged, the resistive type dump load is connected through a switch to consume an excessive power if available. AC kind of loads is operating in three phase distribution system. Hence, an inverter is operated to supply AC power at load bus. In order to provide a quality supply at load bus, an efficient control method is developed on the inverter.

The bidirectional dc-dc circuit is incorporated to manage current flow of the battery and the control method of this converter is designed for mainly manage the charging and discharging requirement of the battery in the standalone system. An effective control management system is developed on the battery controller. The same controller is working based on regulation of voltage at the dc-link. However, a restive dump load controller will consume surplus power once battery gets full charge, the upper limit of the battery charging status is considered as 80% in this paper (i.e., State of Charge (SOC) = 80%). The main objective of the paper is to maintain energy management system as well as to supply quality power at load bus under various operating conditions.

The key problem with a PMSG coupled standalone wind power supply system is controlling the inverter to provide clients with a balanced supply voltage under various changes in the system. Furthermore, flickers, harmonic production, voltage fluctuations, and load imbalance are the most common power quality (PQ) issues in wind energy conversion system. The voltage fluctuations are mostly caused by changes in load. Variations in wind speed are the primary causes of flicker or voltage fluctuations. The power electronics interface (power converters) between the sources and the loads generates unwanted harmonics. Customers may not accept these power quality issues, necessitating mitigating strategies. The authors of [5] included power management of a stand-alone PV/FC/wind energy system. The authors of [6] described a wind plus PV system that is coupled to dc loads. The authors of [7] described a wind and solar hybrid system with inverter control to manage the voltage and frequency of the output alternating current voltage without the need of any storage device. However, the writers of [5-7] did not pay attention to the numerous power quality issues. As a result, along with voltage and frequency management, power quality issues are examined in this work, and control approaches will be adopted to mitigate their impact.

The proposed controller utilizes the information only about V_{dc} and does not require measurement of other quantities like wind, dump load and load power. The coordination between battery and dump load play important role in power management. When load demand is more than the generation, battery will provide the power. If there is excess energy from wind, it will first pumped into batteries till it reaches its upper limit of SOC and then the excess power is fed to the dump through a chopper circuit. The SOC factor also considered while taking decision of the switching patron. The control method of the chopper can be able to increase the duty cycle once SOC hits its upper limit. With this control strategy the load voltage (or PCC voltage) will be maintained at rated value in spite of variations in both load as well as generation.

The regulation of the magnitude of the output ac voltage using a load side inverter is detailed in Section 2. Section-3 augments a correct energy management approach with the control strategy defined in Section-2 to adjust the output ac voltage when there is a change in wind speed, irradiation, or load. Section-4 investigates the influence of an imbalanced load on the generator and develops a control strategy to manage the battery current in order to eliminate the electrical torque pulsation of the PMSG. Moreover, a pulse width modulation (PWM) based inverter control is incorporated to make the PCC voltages balance even when the load is unbalanced. The detail modeling of the hybrid system is presented in Section-5. The simulation results are shown in Section-6.

2. DC LINK VOLTAGE CONTROL

The PMSG based standalone wind power conversion system with battery, dump load and AC load is shown in Fig. 1. A diode rectifier is used to provide dc-output from three phase power generation from PMSG. A boost converter is incorporated to the diode rectifier for working as a MPPT circuit to extract maximum energy from wind turbine under various wind speeds.

Using a bidirectional circuit, the voltage at battery terminals may be maintained lower than the reference dc link voltage (V_{dc}^{*}), requiring less batteries to be linked in series. In this study, we suggested a single switch and two switch bidirectional DC-DC circuit for battery discharge and charging. As a result, no additional MPPT of PV system is required in this suggested system. Because this DC-DC converters working MPPT of our PV system in this model, that gives good efficiency, no converter loss and economically benefit. In the two switch proposed system battery voltage considered at 300V while V_{dc}^{*} = 664V and in single switch battery voltage is kept at V_{dc}^{*}. In this paper considered 60% depth of discharge (DOD) from [8], is assumed based on even there is no generation from wind, it should be able to meet the energy needs of a 6kW load for around an hour. Appendix discusses the computation of the rating in depth. Figure 2 depicts the control scheme of the dc-dc converter used to manage the discharging/charging process of the battery by regulating voltage at dc-link. Using the output signal of controller as the reference component of battery current, a hysteresis band technique is used to produce signals for Q1 & Q2. Furthermore, the control signal is confined within a certain range so that the actual battery current is within the battery's specifications, resulting in increased battery longevity.

In order to ensure that the modulation index remains within a practical range, it is essential to develop an effective power management scheme that maintains a constant dc bus voltage while keeping the ac output voltage (PCC voltage) of the inverter constant. Within our system (Fig.1), we have three additional devices - battery, dump load, and aqua electrolyzer - alongside solar and wind. Among these three devices, the battery has the capability to function as both a source and a sink. Consequently, it must discharge or charge within specified limits when there is a deficit or surplus of wind energy caused by low or high wind speed. The other two devices, dump load and aqua electrolyzer, can solely serve as system sinks. As a result, if the high power of the sources lasts for a long time and the battery reaches its upper limit of charge storage, the dump load/aqua electrolyzer should activate and use the surplus power available in the wind. According to this research, it is hypothesized that additional energy is initially supplied to the battery until it reaches its maximum capacity for carrying charge. Subsequently, the surplus power is directed towards either the dump load or the aqua electrolyzer, and its regulation is managed by the chopper control (switch S_d in Fig. 1). The decision to activate the control action is determined by comparing the SOC with the battery's upper limit. Figure 3 depicts the control system design. The flow chart of the aforementioned energy management system is represented in Fig. 4, where the upper and lower limits for the battery's SOC are fixed at 0.2 and 0.8, respectively [8]. The suggested energy management algorithm makes use of battery information and SOC and does not need the monitoring of additional parameters like as load power and wind power.

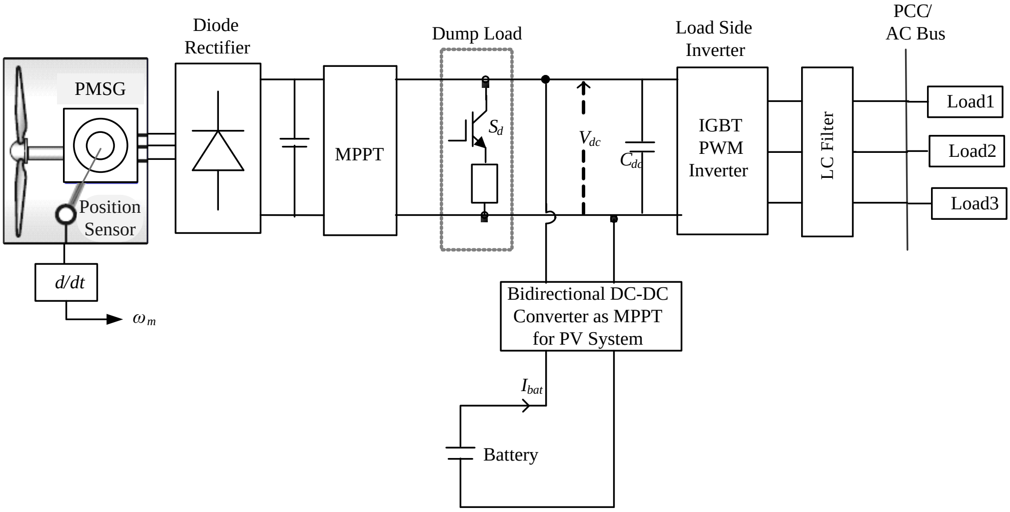

Fig. 1: Standalone Power supply system.

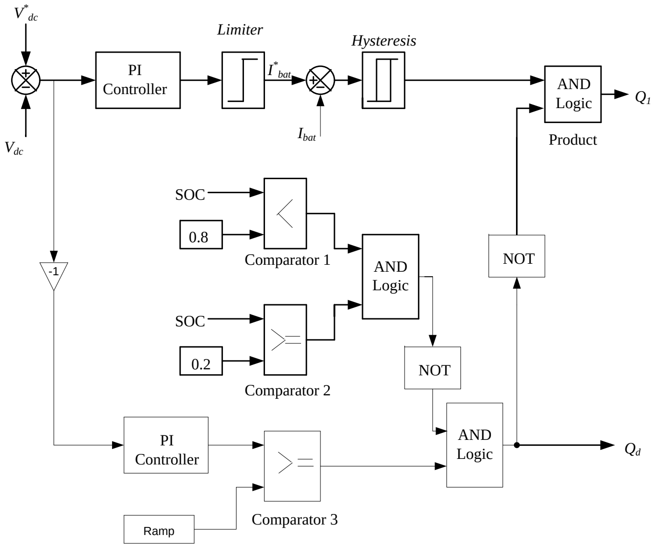

Fig. 2: Dc-dc converter controller.

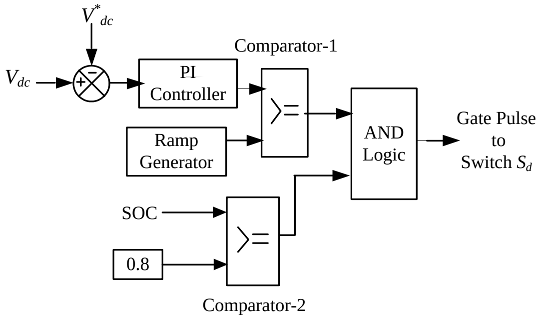

Fig. 3: Dump load controller.

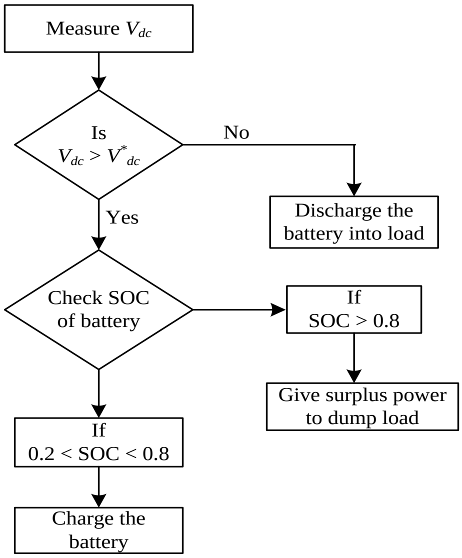

Fig. 4: Energy management algorithm.

3. COMPENSATION FOR UNBALANCED LOAD

Because the loads in distribution systems are typically single phase, currents in various phases will not be equal. The following are the negative impacts of unbalanced current on the producing system

- Pulsations in electrical torque.
- Unbalanced voltages at load bus.

The influence and control of the two quantities listed above are addressed further below.

(A) Impact on generator torque and compensating

The temporal variation of dc link current (I_d) and dc link voltage (V_{dc}) may be described as a dc component overlaid with a second-harmonic component during unbalanced currents produced by an inverter, as stated in the literature [12]. Because of the presence of a 2nd-harmonic component in the dc link, the generator's shaft life span will reduce due to oscillations. In this study, a dc-side filter is designed to decrease oscillations in the generator's electrical torque. The dc-side active filter is implemented as a dc-dc error is processed by hysteresis, which then provides control signals (gating pulses) to the dc-dc converter's IGBT devices (Q1 & Q2) with the help of reference [13]. As a result, the dc-dc circuit control outlined in previous section is adjusted to account for the imbalance load.

(B) The effect on voltage at the PCC and how it is compensated

Because the inverter is linked to an uneven load, the current flowing through each phase may not be equal, resulting in unequal voltage drop across the LC filters utilized in each phase. As a result, the voltage imbalance at PCC must be compensated. To do this, a PI controller is supplied the difference between the rms value of the phase-phase voltage at load bus and the reference phase-phase voltage. To obtain the reference line voltages (v_{ab,bc,ca_ref}), the PI controller output is multiplied by a unit sine wave generator. Using v_{ab_ref}, v_{bc_ref} and v_{cb_ref},. PWM signals are produced to control the activation and deactivation of the inverter on the load side. Figure 5 depicts the control method utilized for imbalanced voltage adjustment. As a result, the rms-based technique is used to derive the reference line voltages in this study. A comparison of various control method is shown in Figure 6.

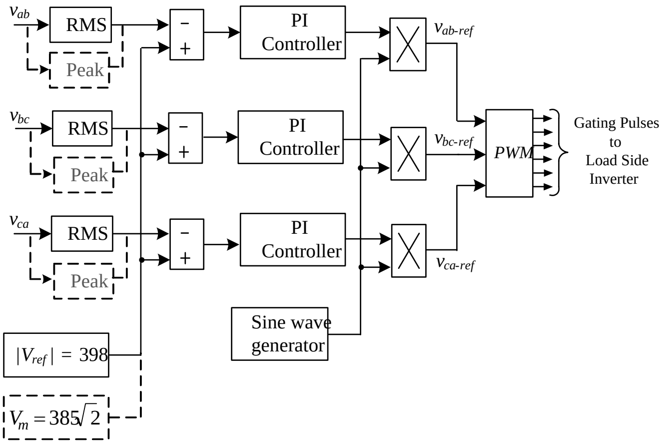

Fig. 5: PWM inverter controller for compensating imbalanced loads.

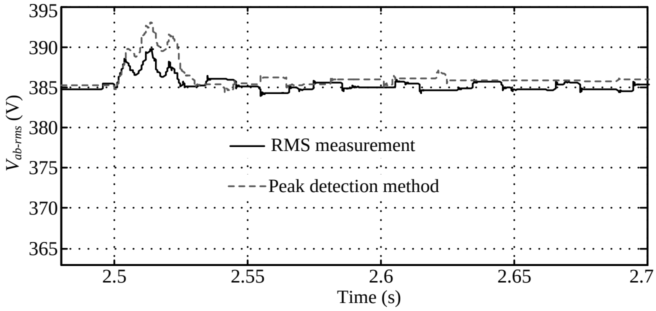

Fig. 6: RMS and peak detection methods are compared under balanced load conditions.

4. OUTCOMES AND DISCUSSION

MATLAB/SIMULINK is used to create the simulation system of the PMSG-based wind power conversion system as shown in Fig. 1. PMSG data is derived from [5] and duplicated in Appendix. Appendix is additionally includes data for both the two mass drive train model and the aqua electrolyzer model. The integral time square error (ITSE) approach is used to optimize the gains of all PI controllers [6]. The presented power supply system's performance is evaluated using the below scenarios:

Case-1: Taking into account fluctuations in load and speed of the wind.

The instants, at which the load variation is evaluated, as well as the amplitude of the variation, are shown below:

Load current = 7.4 A for 2-3s

Load current = 3.7 A for 3-6s

The speed of wind changes and the amount of the change are shown below:

Wind speed = 12m/s for 0-2.5s.

Wind speed = 7m/s during 2.5-5s.

Wind speed = 15m/s for 5-6s.

Figure 7 depicts the response to the mentioned changes in speed as well as load current. Analyzing the behavior of Fig.7, it is clear that the controller's performance in both transient and steady state is fairly excellent. This delay is added into the WECS as a result of the wind turbine's more accurate two mass models. Because the delay is substantially longer than the reaction time of the dc voltage regulator, there is no change in dc voltage when wind velocity changes. Corresponding RMS voltage is depicted in Fig. 8. Alternating current and voltages are shown in Figures 9 and 10 respectively. The output alternating current voltage wind generator and battery for the previously specified load current and wind speed. According to Fig. 11, the battery either supplies or absorbs power based on the difference between the PMSG output power and load demand. The SOC is purposefully kept considerably below 0.8 in the mentioned testing, such that the dump load/auqa-electrolyzer is not turned on, as seen in Fig.3.

In the second experiment, the battery's SOC is initialized around 0.8 with a mild load situation, such that the battery is charged and the SOC reaches 80% limit. Under this situation, excess energy should be sent to the dump load. Figure 12 depicts the transient in (V_{dc}) for a resistive type dump load. In the case of a resistive dump load, (V_{dc}) settles quickly; but, due to the sluggish dynamics of the aqua electrolyzer, (V_{dc}) climbs to 661V as opposed to 640V (V_{dc}).

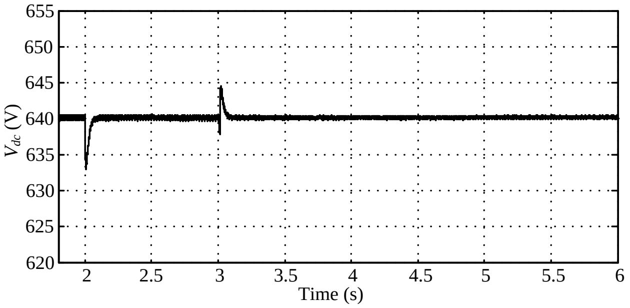

Fig. 7: Voltage.

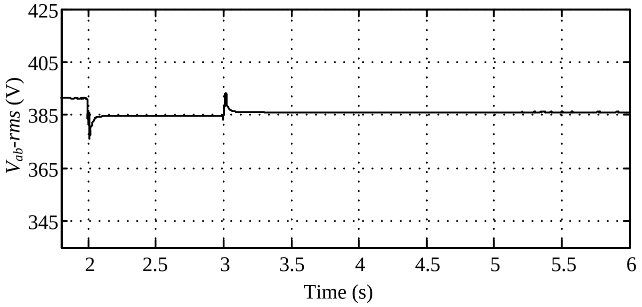

Fig. 8: RMS output voltage (PCC voltage).

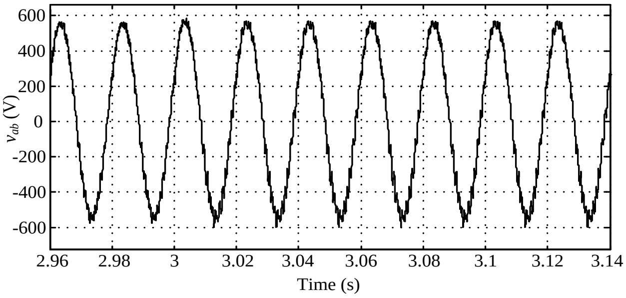

Fig. 9: Instantaneous output voltage at t= 3s.

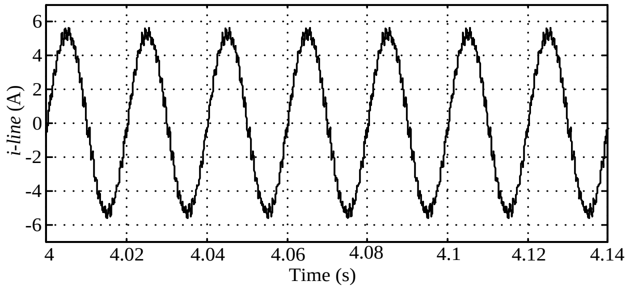

Fig. 10: Instantaneous output line current.

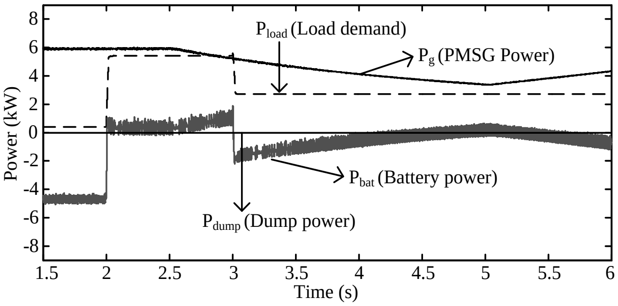

Fig. 11: Powers.

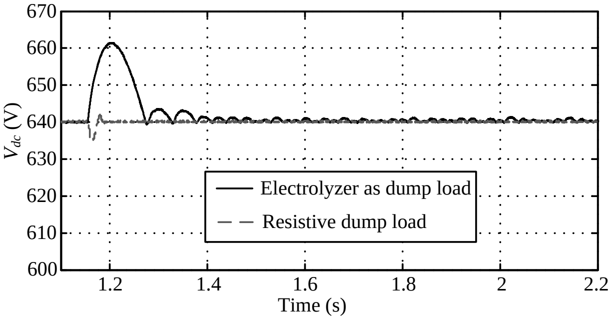

Fig. 12: V_{dc} response when electricity is applied to the electrolyzer.

Case-2: *Under unbalanced load currents.*

Assumed the following imbalanced load currents (Fig. 13):

i_{la} = 3.53 A; i_{lb} = 9.55 A; i_{lc} = 8.45 A.

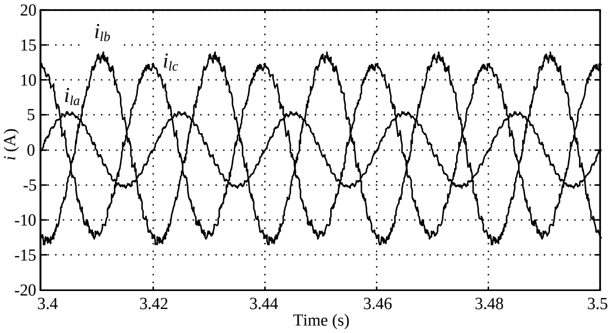

Fig. 13: Unbalanced currents.

Furthermore, as a result of the previously indicated imbalanced load (Fig. 13), the line voltages at PCC (Fig. 14) exhibits some unbalanced nature. The voltage imbalance factor (VUF) is determined to be 2.6%, which is higher than the allowable limit (1%). The suggested PWM inverter control is used to lower VUF to an acceptable level, and the VUF is reduced to 0.15%. Figure 14 depicts the rms voltages of lines and corresponding modulation indices.

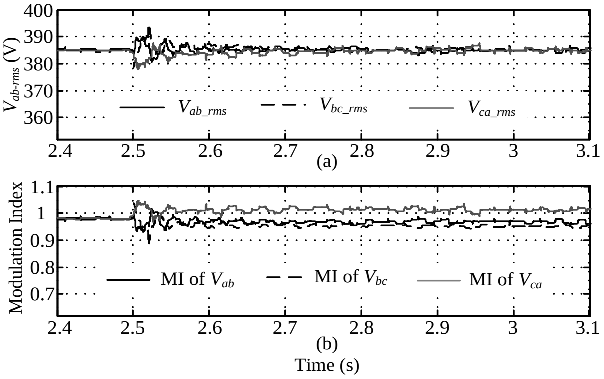

Fig. 14: (a) RMS voltage; (b) modulation indexes.

5. CONCLUSIONS

This research presents control algorithms for regulating voltage of a PMSG based standalone wind power supply system. The simulation results represent that the proposed control method can keep the load voltage stable despite fluctuations in order to changes in load and generation. An algorithm is being created to manage energy between the load, wind system, battery, and dump load/aqua electrolyzer. The suggested energy management flowchart is simple and requires just voltage at dc-link. The effect of imbalanced loads on the generator is investigated, and a dc-dc converter management strategy is developed to mitigate its influence on the generator's electrical torque. PWM inverter control is used to balance the line voltage at the PCC in the event of an imbalanced load. Inverter management also aids in decreasing PCC voltage excursions caused by the sluggish dynamics of the aqua elctrolyzer when power is applied to it. The THD in voltages at PCC is around 5%, indicating that the voltage generated at the consumer end is of high quality. The simulation findings show that the controllers work effectively under steady-state and dynamic settings, as well as under balanced and unbalanced load conditions.

APPENDIX

Calculation for battery rating = $\frac{6\,kW \times 1\,hr}{300\,V \times 0.6} = 33.33\,Ahr$

Hence, rating of the battery is considered as: 35 Ahr, 12 V, and 25 numbers of batteries required in series connection.

The L-C filter is modeled from [11]:

$$K = \left[\frac{k^2 - \frac{15}{4}k^4 + \frac{64}{5\pi}k^5 - \frac{5}{4}k^6}{1440} \right]^{1/2} \tag{16}$$

$$L_f = \frac{V_o}{I_o\, f_s} \left\{ K \frac{V_{dc}}{V_{o,av}} \left[1 + 4\pi^2 \left(\frac{f_r}{f_s} \right)^2 K \frac{V_{dc}}{V_{o,av}} \right] \right\}^{1/2} \tag{17}$$

$$C_f = K \frac{V_{dc}}{L_f\, f_s^2\, V_{o,av}} \tag{18}$$

Parameters of PMSG

No of Poles	10.0
Speed rated	153 rad/s
Resistance Armature (R_s)	425mΩ
Magnetic flux linkage	433mWb
Stator inductance (L_s)	8.4mH
Torque	40Nm
power	6kW

Two Mass Drive Train's details

H_t	4s
H_g	0.1H_t
K_{sh}	0.3p.u./el.rads.
D_t	0.7p.u.s/el.rads.

Parameters of Electrolyzer

R, *L*	68.26 Ω, 13.65 H

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