Advanced Power Flow Management System for Electric Vehicle Charging Station

Abhishek Pratap Singh and Yogendra Kumar

Abstract In this paper, an advanced power management approach is proposed to obtain the adequate power flow control of fusion microgrid (FMG) against variable sources. The FMG is the combination of PV array system and micro gas turbine as power delivered sources. PV system has intermittent input dynamics effects in power vacillations of fusion DC microgrid. Therefore, a hybrid energy storage system (HESS), i.e., combination of battery energy storage system and supercapacitor to overcome such power fluctuations. The intermissive nature of PV system can impel the battery storage of HESS into overcharge/over discharge which again consequences in power vacillation of fusion microgrid. To avoid overcharge/over discharge of battery storage system, advanced power management system (APMS) has employed a state of charge (SOC) indicator which will protect the battery energy storage system. In this paper, to ensure the charging station voltage is constant at the DC bus terminal of FMG through a power balance between source and load with the proposed APMS. The projected method is corroborated with MATLAB /SIMULINK software.

Keywords Advanced power management system · Hybrid energy storage system · Micro gas turbine · Voltage control · Adequate power flow control · Fusion microgrid

1 Introduction

In 21st century, a new transportation sector electric vehicles are rising. To meetup the EV goals, distributed generation in the form of microgrid has installed crosswise in the country. The evolving country are deploying microgrid grid in rural areas and inaccessible locations were electrification difficult. Non-conventional sources of power like solar PV, wind energy, hydro, etc., are available abundantly. In [1, 2], the

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V. Mahajan et al. (eds.), *Sustainable Technology and Advanced Computing in Electrical Engineering*, Lecture Notes in Electrical Engineering 939,
https://doi.org/10.1007/978-981-19-4364-5_4

admittance basic control is used for the adequate power flow of PV-diesel generator-based HMG. However, in this approach, the operational dynamics parameter of diesel generator set is not taken into account. Also, because of inclusion of diesel generator and heavy battery, this approach is not reasonable. In [3–5], the adequate management of power can be attained by governing storage system of battery that is connected to voltage source converter. Yet, the power-driven functioning dynamics of hydro generator is not taken into account by the suggested topology. The profound charging and discharging situation of battery energy storage system is ignored in the suggested power managing procedures in [6, 7] that are hardware based. In [8, 9], a multi-docks converter is accustomed for the managing the power of solar PV-battery storage system-based hybrid microgrid. In [10], for maintaining the adequate control of power flow of HMG with load fluctuation, a dynamic power management algorithm is suggested. Also, the profound discharging and charging levels of HESS are taken into account by this control process. However, this procedure does not take into account any revolving machine dynamics. In [11], for balancing load demand power, a hybrid MG structure shown in [10], and a hybrid ESS interfaced with multi-level inverter (MLI) is accustomed. However, for projected fusion microgrid based electric vehicle charging station shown in Fig. 1, this procedure is not applicable. The operational parameters of hydro energy-based generators are not taken into account by the power management procedure suggested in [2, 5]. Furthermore, vast range of load power variations is not taken into account by these control procedures. Electric vehicles charging stations have categorized in slow, moderate, and fast charging modes. Charging time of EVs is crucial whenever public charging station is used. So, to maintain charging time, rated capacity of charging station must be constant irrespective of load demand because charging duration of electric vehicle is inversely proportional to charging capacity.

So, to maintain the rated capacity of charging station source active power fluctuation should be minimized. In all the literature, DC microgrid installed with battery for a DC load but ignores to manage solar power fluctuation and battery stress level. The contribution of the paper is as follows:

- A fusion microgrid based charging station power management with help of MGT, solar PV system, and HESS.
- To protect the battery from overcharging and discharging with the help of SOC indicator.

2 Modeling of Fusion Microgrid

In this section, some important equation of mathematical modelling of PV array system, micro gas turbine (MGT) based permanent magnet synchronous generator, and hybrid energy storage systems (HESS).

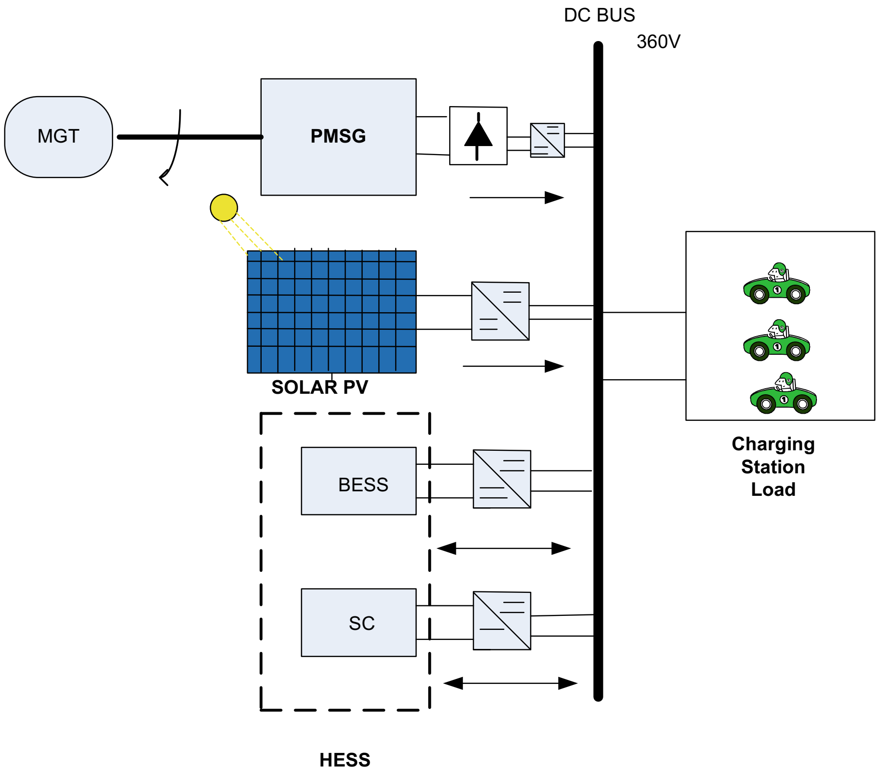


Fig. 1 Proposed electric vehicle charging station

2.1 PV Array System

PV array system is modeled with number of series and parallel modules. Desired voltage and current level of photovoltaic (PV) system depend upon the number of series and parallel modules. Maximum power point tracking (MPPT) algorithms is helps to maximize the power of PV system. This paper, incremental conductance MPPT technique is used for take-out maximum output power from the system. The incremental conductance algorithm is shown in Fig. 2. In this algorithm, the output voltage of the photovoltaic system determines by comparison with the Incremental conductance and instantaneous conductance of PV modules. If the value of conductance is equal, then it shows the maximum power point (MPP) for a particular given irradiance value (W/m^2). The power output of PV system is obtained by

$$P_{pv} = v_{pv} * i_{pv} \tag{1}$$

The duty cycle of unidirectional PV system converter is calculated by

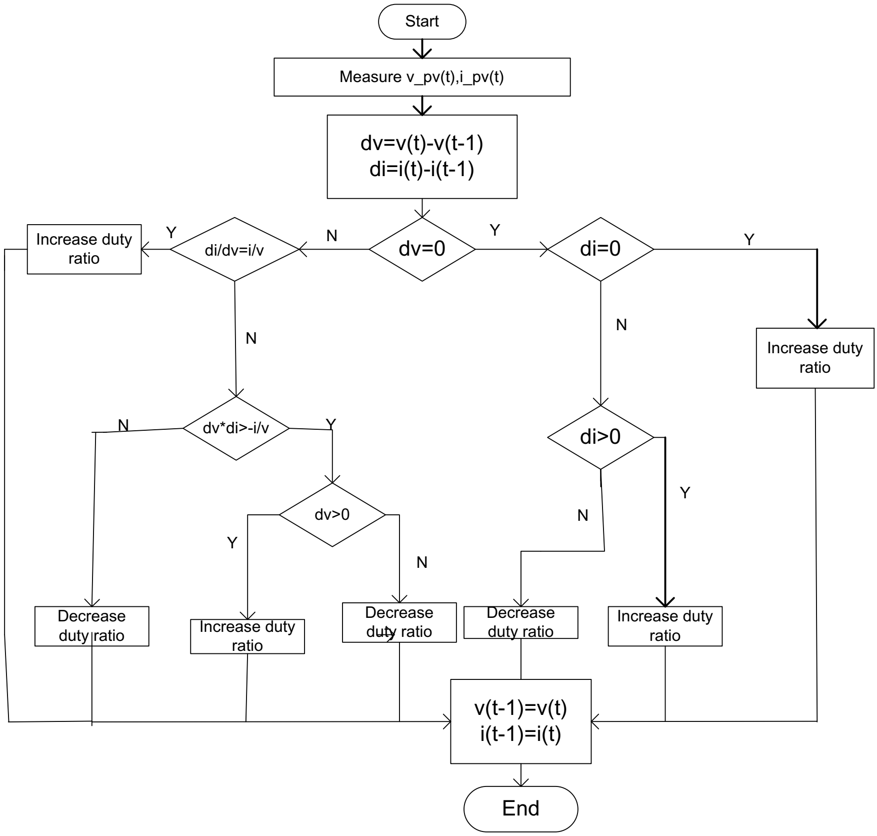


Fig. 2 Incremental conductance MPTP algorithm

$$\begin{aligned} \text{Dc} &= \frac{V_{dc} - V_{in}}{V_{dc}} \\ &= 1 - 253/360 \\ &= 0.2972 \end{aligned} \tag{2}$$

The inductance of converter is calculated by

$$\text{Lc} = \text{Dc} * (\text{Vdc} - \text{Vin}) \tag{3}$$

where,

Dc = duty cycle of PV system converter

Vin = input voltage of PV system

Vdc = voltage at the bus terminal.

2.2 Modeling of Micro Gas Turbine (MGT)

The micro gas turbine has very high speed and small power capacity. MGT contributed power to FMG. The MGT with semi-Kaplan-PMSG, supply DC power to FMG without any interruption. A common type of single-reheat tandem compound turbine is used in hybrid system. The response of a steam turbine has better when compared with a hydraulic turbine due to water inertia. A simple transfer function of turbine derived by using turbine torque (ΔTm) and control valve position (ΔVcv) is follows:

$$\frac{\Delta T_m}{\Delta V_{cv}} = \frac{1 + SF_{HP}T_{RH}}{(1 + ST_{CH})(1 + ST_{RH})} \tag{4}$$

The electromagnetic torque produced by the PMSG is:

$$T_e = \frac{3}{2}\frac{P}{2}[\varphi_m i_q \left(L_q - L_d\right) i_q i_d] \tag{5}$$

where,

P is number of poles, L_d and L_q are d_q frame inductance, i_d and i_q are d_q frame current, and φ_m is flux linkage.

2.3 Modeling of HESS

The intermittent input solar dynamics causes the voltage fluctuation of DC microgrid. To maintain the DC microgrid stable operation, HESS supports to microgrid. HESS is combination of Li-ion battery and supercapacitor. HESS compensates the source side power dynamics which is slow varying power dynamics compensated by battery storage system and very fast power variations are supported by supercapacitor (SC) storage system. But, overcharging and deep discharging of battery may harmful for battery life. Thereby a voltage limits of BSS are predefined for this work which indicates overcharging and deep discharging of BSS.

The power compensated by HESS is given by equation:

$$\Delta P_c = P_{MGT\_DC} \pm P_{PV} - P_L \tag{6}$$

$$P_b = \frac{\Delta P_C}{1 + ST_b} \tag{7}$$

$$P_{SC} = \Delta P_c - P_b \tag{8}$$

where

ΔP_c = power compensated by HESS

P_b and P_{sc} = Reference's power of battery and supercapacitor, respectively

P_L = rated power capacity demand (kw)

T_b = battery response time.

3 Advanced Power Management System (APMS)

In all the literature DC microgrid installed with battery for a DC load but ignores to manage solar power fluctuation and battery stress level simultaneously.

The proposed advanced power management system shown in Fig. 3 operates based on net zero power concept, i.e., difference between local power generation and local power utilization is zero. In this paper, adequate power flow control of DC microgrid is obtained by

$$P_{MGT\_DC} + P_{PV} \pm P_{ESS} - P_L = 0 \tag{9}$$

For the stable operation of hybrid microgrid. Output voltage of MG should maintain constant. That's why power generation and load demand should be equal. Optimal power flow control is obtained by

$$P_{ref}(K) = \Delta P_{PV_{J-1}} + \Delta P_{PV_J} + \Delta P_C \tag{10}$$

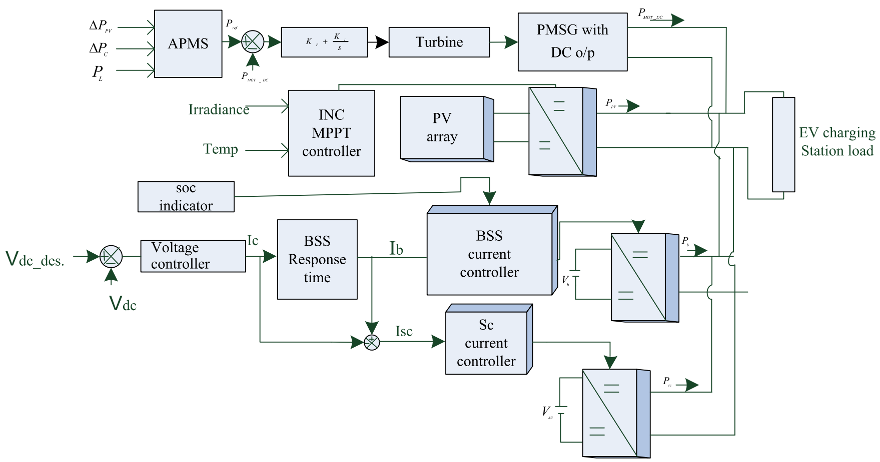


Fig. 3 Block diagram of proposed APMS

$$\Delta P_{PV_J} = P_{PV_J} - P_{PV_{J-1}} (\text{for}, \text{J} > 1) \quad (11)$$

Power monitoring block continuously monitors the power generation and load side demand. Reference active power supported by the micro gas turbine.

4 Results and Discussion

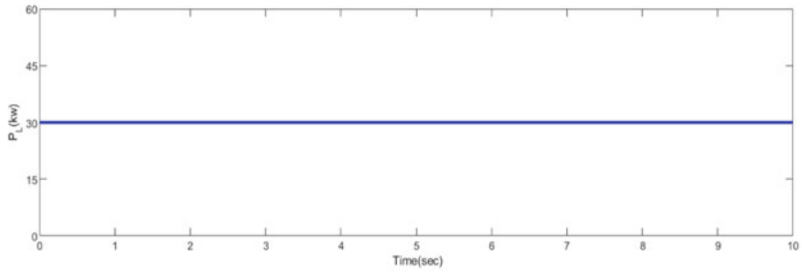
In this section, the results are attained with APMS for power balance of a fusion microgrid. In Fig. 4a shows a constant 30 kW EV charging load demand. In Fig. 4b shown output power of photovoltaic system fluctuates in every 2 s, so after $t = 2$ s, there is no support of power from photovoltaic system. HESS has supported this source power variation to fulfill 30kw charging load demand. But, Li-ion battery has some response time so that battery cannot support instantly that's why a supercapacitor storage device is used for quick response. Figure 4c, d shown 20 kW active power support from HESS to FMG from $t = 2$ s to t = 4 s, respectively.

At $t = 4$ s PV array output power has abruptly risen to 20 kW. This irregularity has led the battery overcharged it's clearly shown in Fig. 4d. because of sudden increase in output power of photovoltaic system Li-ion battery has been over charged up to—13.6 kW (at $t = 4$ s). Same Li-ion battery charged with APMS reduces—10.3 kW from $t = 4$ s to $t = 5$ s as shown in Fig. 4h.

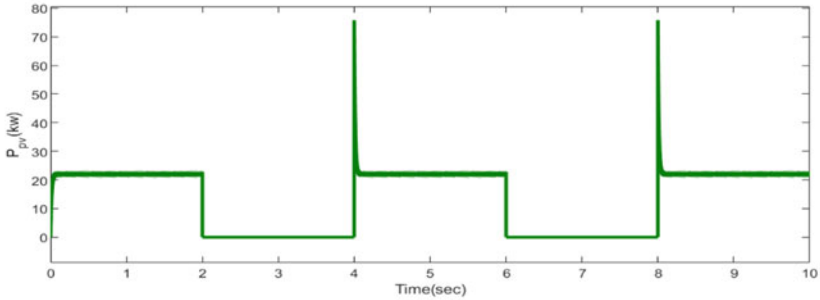
So that it is concluded from Fig. 4d, h the energy stress of battery reduces by 24.2%. The irregular behavior of PV array output power voltage of DC microgrid oscillates at $t = 2$ s and $t = 4$ s as shown in Fig. 4b. Because of voltage variation, output power of DC microgrid can varied. APMS has resolved initial voltage oscillation and voltage spike and get a smooth desired 360 V DC output voltage as shown in Fig. 4g. The total EV charging load demand is 30kW. PV array system and ESS combinedly support 20kw without any interruption in DC grid voltage. And remaining 10kW supported by micro gas turbine based permanent magnet synchronous generator as shown in Fig. 4e. Micro gas turbine supplies reference active power estimated by APMS.

5 Conclusion

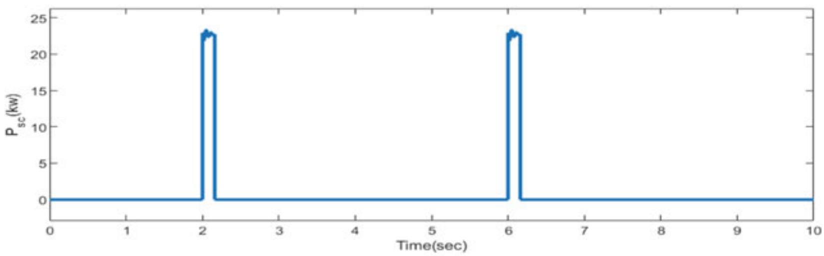
The advanced power management system introduced in this paper has ensure power balance between multiple sources of fusion microgrid and load demand. Due to variation of PV array output power, microgrid output voltage fluctuates so that output power is also affects. Thus, to avoid this noxious of fusion microgrid, APMS has managed by using of battery and super capacitor based mixed energy storage system have been taken into account in this work to counteract the power fluctuations by disintegrating into slow and fast variation. Results are presented in this work; it



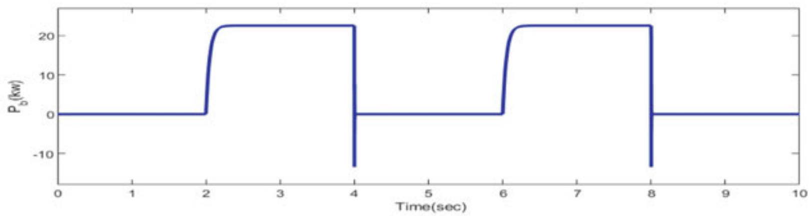
(a)



(b)

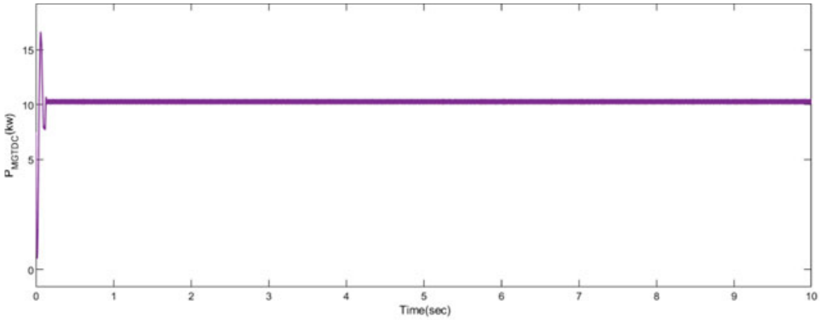


(c)

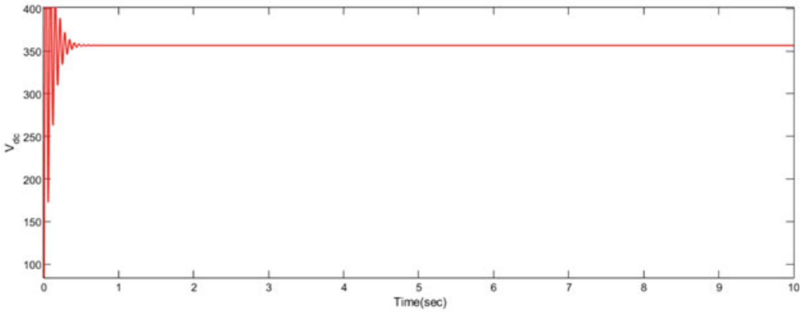


(d)

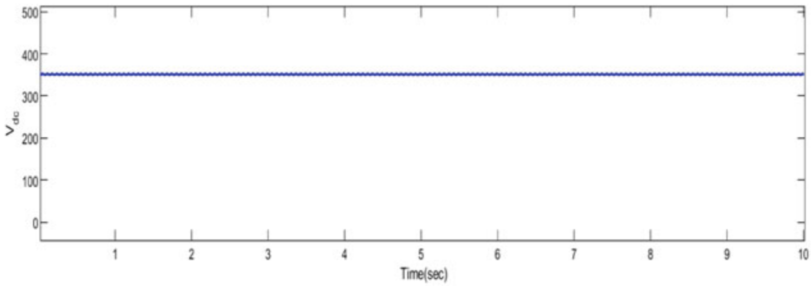
Fig. 4 **a** Constant EV charging station load demand. **b** PV array system output power. **c** Output power of supercapacitor. **d** Output power of battery without APMS. **e** DC power output of MGT based PMSG with APMS. **f** Output voltage (V_{dc}) without APMS. **g** Output voltage (V_{dc}) with APMS. **h** Output power of battery with APMS



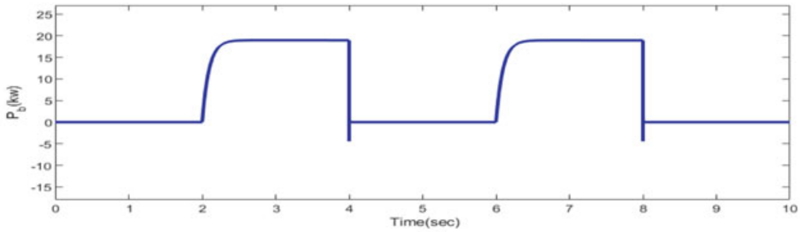
(e)



(f)



(g)



(h)

Fig. 4 (continued)

is noticed that with APMS voltage oscillation reduces and charging station power demand remains constant. Stress level is reduced to 20.7% as compared to without APMS. The slow power variation is compensated by battery, and fast power variation is compensated by super capacitor. MGT supported all the time reference power with a constant magnitude. In this paper, APMS validated only for constant charging station load. In the future, it can be extended for a variable charging station load.

Appendix

PMSG: 400 V, 30 KW, 1500 r.p.m.

MGT: fuel pressure = 358–380 kPa, fuel flow = 12 m^3/h

PV array system: $v_{pv} = 255\text{V}$, $i_{pv} = 100\text{A}$

Battery Li-ion: Nominal voltage = 205 V, 140 Ah, $V_{b\text{Max}} = 220\text{V}$, $V_{b\text{Min}} = 190\text{V}$

Supercapacitor: 245 V, 120 F.

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