Middle-East Journal of Scientific Research 25 (2): 296-303, 2017
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2017.296.303

High Performance Supervisor Controller with Multimode Operation of a Hybrid System for Multi Grid Applications

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Abstract: This paper presents a new power – control strategies of a grid –connected hybrid generation and energy storage system with flexible power transfer. The hybrid system consists of Wind System, Solar System, storage devices: Battery and Super capacitor (SC). Here the system is connected to Three Phase or Single Phase Grid based on the total amount of power generated. Various modes of operation were proposed. The Supervisor Controller directs the mode of operation of both generation subsystems and also manages the change from power regulation to MPPT based power conversion. The final conclusion is based on the system variables as presented. The main objective is to satisfy the total power demand and also extend the life of the batteries by maintaining the State of Charge (SOC) value .It was observed that the Supervisor Controller assigns the sources optimally conferring to the demand and availability. From the simulation we are able to see the performance of the system. This helps you to check how the system is being supplied and which source of energy is the most dexterous in supplying the load.

Key words: Wind Turbine · Photovoltaic Array · Battery · Super capacitor · Supervisory Controller · Inverter · Grid Integration

INTRODUCTION

The expertise of integrating the renewable energy sources (RES) and Energy Storage System (ESS) has become the latest trend in power electronics. For a decade combining multiple renewable energy sources via a common DC bus has been widespread than common AC bus because of easy monitoring and control. Combining added renewable energy storage and Distributed Generator (DG) system requires new approaches for their operations in order to maintain/ advance the power quality and power stability [1]. The vibrant performance of a stand-alone wind and solar system with battery storage was analysed [2]. A wind turbine system model was developed and compared with a real system. The stable state presentation of a grid-connected wind and photovoltaic (PV) array with battery storage was investigated [3]. A grid connected arrangement can lead to grid instability or even failure if they are not suitably controlled.

Various applications are for stand-alone operation, where the core control is to balance local loads. But off-grid operations are originally considered to meet local load demands with a loss of power supply. Such systems do not care much about the flexibility or quality of power delivered to the grid. Most of the users will prefer a hybrid system that can provide multiple modes of operation for power transfer because it will be favourable in operation and also in maintenance. The control strategies of the hybrid system will be entirely different from the conventional systems.

Fig. 1 represents the multimode – multi grid hybrid system. The hybrid system consists of a PV array, Wind Turbine with PMSG, Energy Storage System, a DC bus, Power electronic Converters, Supervisor controller for controlling the power associated with the hybrid energy sources and a grid interface inverter. A Photovoltaic system consists of a PV array, a Boost Converter for boosting the generated Voltage. The wind system consists of Permanent magnet synchronous

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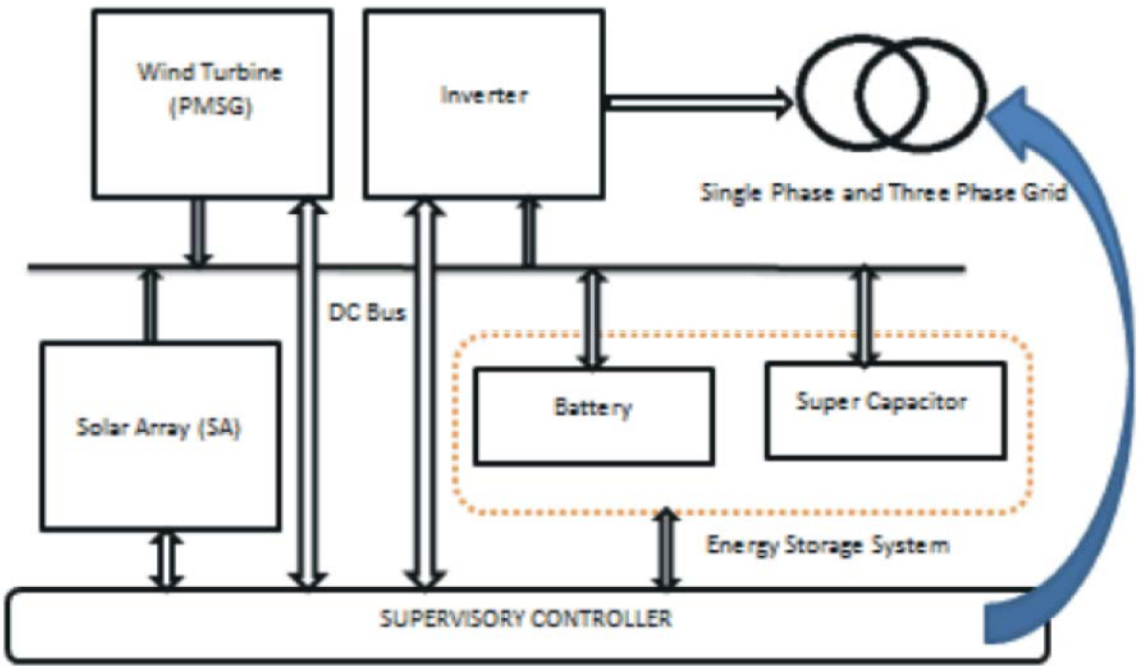

Fig. 1: Multimode – Multi Grid Hybrid System

Generator (PMSG), wind turbine, AC/DC converter for regulating the power. The Energy Storage System (ESS) consists of a battery and a Super capacitor. Super capacitor is recently used as wild dynamic energy storage device, particularly for smoothing fluctuant energy production like wind energy generators. They have very fast charging and discharging capability without memory effect and even it has 100% depth of Discharge(DOD) [4] [5]. The energy storage consisting of flow battery storage and a Super capacitor is described in [6]. Different control strategies were proposed for battery – super capacitor hybrid energy storage [7]. In [8] the fluctuation of battery current flowing in/out is minimized by the optimization Technique. The optimized parameters for one system may not be suitable for another. The grid connected hybrid system is not simply an area of research. There are abundant challenging problems from the control design point of view.

This paper ”High Performance Supervisor Controller for Multimode operation of a Hybrid System with multi Grid Integration” unlike conventional system, this system will overcome various problems by using effective Energy Storage System (ESS) and Power Management Strategies (PMS). [9-12], [13-15]. Such a control Scheme can be tackled thanks to the cost reduction and improvement of power semiconductors. The inclusion of electrical control permits a higher degree of flexibility and more complex objectives can be achieved, particularly in variable-speed operation control [16-19]. With these technological improvements at hand, Supervisory controllers for WECS can be updated by the development of more efficient strategies based on modern control techniques such as: fuzzy logic control [20], robust control [21] and adaptive control [22]. However, controlling a multi-grid is a challenging task. This system can operate in eight different modes such as Mode I - IV for Three Phase Gird and Mode V – VIII for Single Phase Grid. Mode I is a three phase Single source Power regulation Mode, Mode II is a three phase Single source MPPT tracking Mode, Mode III is a three phase Hybrid Power regulation Mode, Mode IV is a three phase Hybrid MPPT tracking Mode. Mode V is a Single phase Single source Power regulation Mode, Mode.

VI is a Single phase Single source MPPT tracking Mode, Mode VII is a Single phase Hybrid Power regulation Mode, Mode VIII is a Single phase Hybrid MPPT tracking Mode, Mode IX is a Grid mode. Recent technique is used for Maximum Power Point Tracking (MPPT) in wind turbine and PV array control. The paper is organised as follows. Section II describes the co-ordinated control strategies for a hybrid system. Section III describes the experimental results.

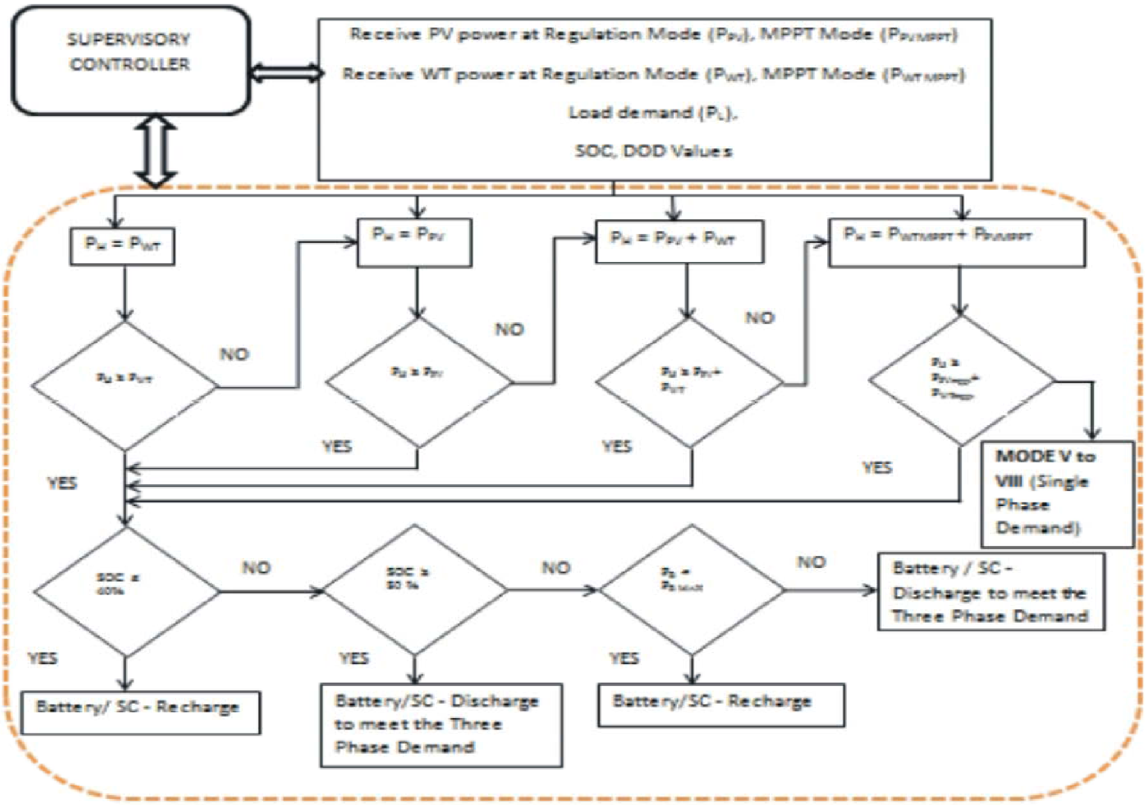

Fig. 2: Control Scheme for Various Modes of Operation

Co-Ordinated Control Strategies for a Hybrid System Various Modes of Operation: Fig. 2 represents the various modes of operation based on the availability and load demand. The supervisor controller monitors parameters of the local controllers and direct the control according to the mode selected. This is designed to perform instant power balancing of the entire Hybrid System so as to satisfy the Grid requirements. These are real and reactive power references, which are obtained from the droop controllers [23, 24]. The power sharing level coordinates the power flow connections among the dissimilar energy sources with different power balancing strategies as developed by Peng Li [25].

Mode I: Three Phase Single Source Power Regulation Mode

In this mode wind system is turned ON and solar system is turned OFF. The wind system first operates in the power regulation mode. Check whether the generated power satisfies the demand. If the generated power is more than the load power i.e., $P_w > P_L$ then the battery and super capacitor gets charged. If the power generation doesn't satisfy the demand, then the control changes to Maximum power (MPPT) Mode. Also it makes use of battery and super capacitor to Charge/discharge with safe SOC / DOD value Even then if there is a demand then switch to mode II.

Three Phase Power, $P_w \geq P_L$

Wind Subsystem:

(i) Power Regulation $P_{wref1} = V_b\,(I_L + i_{bref})$

(ii) MPPT $P_{wref2} = (k_{opt} * \omega_m^3) - 3/2(i_q^2 + i_d^2)\, r_s$

Solar Subsystem: Inactive

Battery Bank: Charging/Discharging

Mode II: Three Phase Single Source MPPT Tracking Mode

In this mode solar system is turned ON and wind system is turned OFF. The Solar system first operates in the power regulation mode. Check whether the generated power satisfies the demand. If the generated power is more than the load power i.e., $P_s > P_L$ then the battery and super capacitor gets charged. If the power generation doesn't satisfy the demand, then the control changes to Maximum power (MPPT) Mode. Also make use of battery and super capacitor to Charge/discharge with safe SOC / DOD value. Even then if there is a demand then switch to mode III.

Three Phase Power, $P_s \geq P_L$
Wind Subsystem: Inactive
Solar Subsystem:
(i) Power Regulation $P_{sref1} = V_b\ (I_L + i_{bref})$
(ii) MPPT $P_{sref2} = (\delta I_{pv}/\delta V_{pv}) - (I_{pv}/V_{pv}) = 0$
Battery Bank: Charging/Discharging

Mode III: Three Phase Hybrid Power Regulation Mode

In this mode both solar and Wind system is turned ON. The Hybrid system operates in the power regulation mode. Check whether the generated power satisfies the demand. If the generated power is more than the load power i.e., $P_w + P_s > P_L$ then the battery and super capacitor gets charged. If the power generation doesn't satisfy the demand then the battery and super capacitor are made to discharge to satisfy the demand with safe DOD value. Even then if there is a demand then switch to mode IV.

Three Phase Power, $P_w + P_s \geq P_L$
Wind Subsystem:
Power Regulation $P_{wref1} = V_b\ (I_L + i_{bref})$
Solar Subsystem:
Power Regulation $P_{sref1} = V_b\ (I_L + i_{bref})$
Battery Bank : Charging/Discharging

Mode IV: Three Phase Hybrid MPPT Tracking Mode

In this mode both solar and Wind system is turned ON. The Hybrid system operates in the Maximum Power Point mode. Check whether the generated power satisfies the demand. If the generated power is higher than the load power i.e., $P_{w\,(MPPT)} + P_{s\,(MPPT)} > P_L$ then the battery and super capacitor gets charged. If the power generation doesn't satisfy the demand then the battery and super capacitor are made to discharge to satisfy the demand with safe DOD value. Even then if there is a demand then switch to mode V.

Three Phase Power, $P_{w\,(MPPT)} + P_{s\,(MPPT)} \geq P_L$
Wind Subsystem:
MPPT $P_{wref2} = (k_{opt} * \omega_m^3) - 3/2(i_q^2 + i_d^2)\ r_s$
Solar Subsystem:
MPPT $P_{sref2} = (\delta I_{pv}/\delta V_{pv}) - (I_{pv}/V_{pv}) = 0$
Battery Bank: Charging/Discharging

Mode V: Single Phase Single Source Power Regulation Mode

In this mode wind system is turned ON and solar system is turned OFF. The wind system first operates in the power regulation mode. Check whether the generated power satisfies the demand. If the generated power is more than the load power i.e., $P_w > P_L$ then the battery and super capacitor gets charged. If the power generation doesn't satisfy the demand, then the control changes to Maximum power (MPPT) Mode. Also make use of battery and super capacitor to Charge/discharge with safe SOC / DOD value. Even then if there is a demand then switch to mode VI.

Single Phase Power, $P_w \geq P_L$
Wind Subsystem:
(i) Power Regulation $P_{wref1} = V_b\ (I_L + i_{bref})$
(ii) MPPT $P_{wref2} = (k_{opt} * \omega_m^3) - 3/2(i_q^2 + i_d^2)\ r_s$
Solar Subsystem: Inactive
Battery Bank: Charging/Discharging

Mode VI: Single Phase Single Source MPPT tracking Mode

In this mode solar system is turned ON and wind system is turned OFF. The Solar system first operates in the power regulation mode. Check whether the generated power satisfies the demand. If the generated power is more than the load power i.e., $P_s > P_L$ then the battery and super capacitor gets charged. If the power generation doesn't satisfy the demand, then the control changes to Maximum power (MPPT) Mode. Also make use of battery and super capacitor to Charge/discharge with safe SOC / DOD value. Even then if there is a demand then switch to mode VII.

Single Phase Power, $P_s \geq P_L$
Wind Subsystem: Inactive
Solar Subsystem:
(i) Power Regulation $P_{sref1} = V_b\ (I_L + i_{bref})$
(ii) MPPT $P_{sref2} = (\delta I_{pv}/\delta V_{pv}) - (I_{pv}/V_{pv}) = 0$
Battery Bank: Charging/Discharging

Mode VII: Single Phase Hybrid Power Regulation Mode

In this mode both solar and Wind system is turned ON. The Hybrid system operates in the power regulation mode. Check whether the generated power satisfies the demand. If the generated power is more than the load power i.e., $P_w + P_s > P_L$ then the battery and super capacitor gets charged. If the power generation doesn't satisfy the demand then the battery and super capacitor are made to discharge to satisfy the demand with safe DOD value. Even then if there is a demand then switch to mode VIII.

Single Phase Power, $P_w + P_s \geq P_L$
Wind Subsystem:
Power Regulation $P_{wref1} = V_b\,(I_L + i_{bref})$
Solar Subsystem:
Power Regulation $P_{sref1} = V_b\,(I_L + i_{bref})$
Battery Bank: Charging/Discharging

Mode VIII: Single Phase Hybrid MPPT Tracking Mode

In this mode both solar and Wind system is turned ON. The Hybrid system operates in the Maximum Power Point mode. Check whether the generated power satisfies the demand. If the generated power is higher than the load power i.e., $P_{w\,(MPPT)} + P_{s\,(MPPT)} > P_L$ then the battery and super capacitor gets charged. If the power generation doesn't satisfy the demand then the battery and super capacitor are made to discharge to satisfy the demand with safe DOD value. Even then if there is a demand then switch to mode IX.

Single Phase Power, $P_{w\,(MPPT)} + P_{s\,(MPPT)} \geq P_L$
Wind Subsystem:
MPPT $P_{wref2} = (k_{opt} * \omega_m^3) - 3/2(i_q^2 + i_d^2)\, r_s$
Solar Subsystem:
MPPT $P_{sref2} = (\delta I_{pv}/\delta V_{pv}) - (I_{pv}/V_{pv}) = 0$
Battery Bank: Charging/Discharging

Mode IX: Grid Mode

In this mode if the generated power doesn't meet the load, then the supervisor control allows the grid to start sharing the load gradually from the battery to supply the power demand.

Single Phase Power,
$P_{w\,(MPPT)} + P_{s\,(MPPT)} + P_b + P_{SC} < P_L$
Wind Subsystem:
MPPT $P_{wref2} = (k_{opt} * \omega_m^3) - 3/2(i_q^2 + i_d^2)\, r_s$
Solar Subsystem:
MPPT $P_{sref2} = (\delta I_{pv}/\delta V_{pv}) - (I_{pv}/V_{pv}) = 0$
Battery Bank: Fully Discharged
Grid: Active

Energy Managemant Algorithm: This algorithm is used to (i) balance the power of the entire Hybrid system, (ii) Operate Wind Turbine with Variable speed (Regulation Mode and MPPT Mode), (iii) Avoiding high frequency ripple currents and high DOD values. These objectives will reduce the battery stress and increase the battery Life. The input to this algorithm is selected as Power Demand (P_H-P_L), the optimal wind power and optimal solar power. From these values the input signals for the battery and super capacitor is derived. The demand mismatch is split in to two frequency components through high-pass filter. This is used to find the capacitor reference currents which is compared with actual current and is used to generate switching signals to the converters.

Battery Charging / Discharging: Fig. 2. shows the complete control scheme of a Hybrid System. The suggested supervisory control monitors the values of the variables from the local controllers and performs three main functions.

- Determination of Operating modes
- Calculation of SOC and DOD
- Charging / Discharging of ESS

As there are two storage devices in ESS connected to the DC bus. Supervisory control was designed to regulate their charging and discharging in harmonized manner so as to maintain the life of the battery without compromising the common DC voltage. To do so, several remedies were put on:

- In Normal mode of Operation, the batteries SOC's are enforced to asymptotically approach each other by its resistance value using an optimization technique.
- Battery with high initial SOC is the first to be charged fully.
- If the power generation is more in the system, then batteries are kept fully charged.
- Once if both the batteries are fully charged, the one that was first charged is the one to start discharging first.

- If one battery is charged, it will start discharging once the SOC value of the other falls below 90%.

If the above said conditions are followed, the batteries will be completely charged in a Round-Robin manner.

Super Capacitor Charging / Discharging: Super capacitor is one of the energy storage devices with High power density, used for peak power levelling. It has much higher life cycle than batteries. Super capacitor voltage changes linearly with its state of charge,

$$E_{max} = \frac{1}{2} C v^2 \quad (1)$$

where, C is the Equivalent total capacity of Super capacitors bank.
v is the instantaneous voltage measured at its terminals
E_{max} is the maximum stored energy obtained for V_{max}

Supervisory control controls the operation of the super capacitor and battery in order to maintain the life of the battery. In this paper, to ensure good performances and a sufficient lifetime of super capacitor and to avoid overcharging the maximum voltage was limited to V_{max} and the discharge rate is fixed at 0.25.

Experimental Results: In order to verify the proposed control strategy, the simulation model for this has been built using MATLAB/Simulink. The maximum power of PV array was set to 350W, while the power of WTG was set to 200W. Supervisory control was developed in MATLAB/State flow.

During Mode I, the charging token will be occupied by the battery with higher initial SOC, which is Battery in this case. If necessary, MPPT algorithm for WTG is ON. The power differences between powers demanded by loads and produced one is handled by ESS. Here there is a surplus of available production and the batteries are charging. If the production decreases, the system control transfer to Mode II.

During Mode II, the charging token will be occupied by the battery with higher initial SOC, which is Battery in this case. If necessary, MPPT algorithm for PV array is ON. The power differences between powers demanded by loads and produced one is handled by ESS. Here there is a surplus of available production and the batteries are charging. If the production decreases, the system control transfer to Mode III.

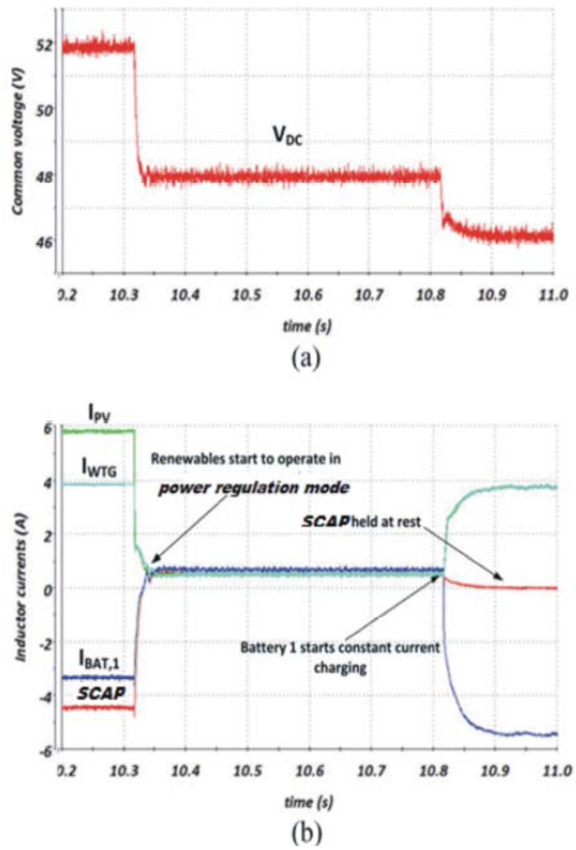

Fig. 3: Results for transition from Mode I to Mode II. (a) Common dc voltage. (b) Inductor currents.

During Mode III, the charging token will be occupied by the battery with higher initial SOC, which is Battery in this case. The power differences between powers demanded by loads and produced one is handled by ESS. Here there is a surplus of available production and the batteries are charging. If the production decreases, the system control transfer to Mode IV.

During Mode IV, the MPPT algorithms for PV array and WTG are ON. The power differences between powers demanded by loads and produced one is handled by ESS. Here there is a surplus of available production and the batteries are charging. If the production decreases, the system control transfer to Mode V.

For all the above cases, if the battery is fully charged, the discharging token is given to it.

In mode V- VIII, the same procedure is repeated for a Single Phase Grid. In Mode IX, supply is taken from grid and satisfies the demand.

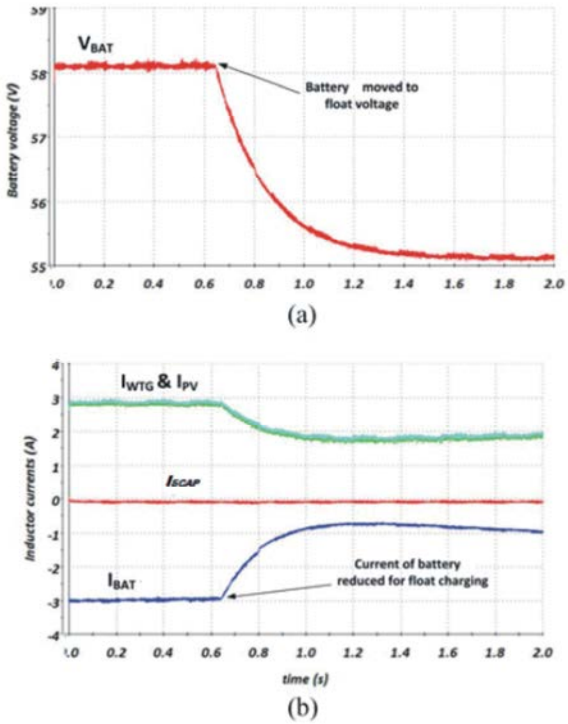

Fig. 4: Transition from boost for float charging in Mode II. (a) Battery voltage. (b) Inductor currents.

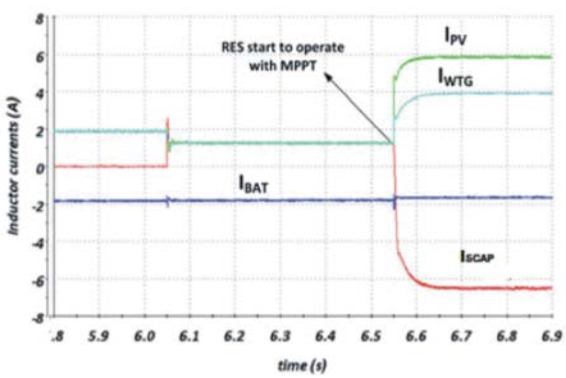

Fig. 5: Inductor currents at MPPT mode

If there is a surplus of available production, the batteries are allowed to charge. When the voltage of battery reaches maximum value, then the batteries are kept in floating condition. The remaining generated power is transferred to the load.

CONCLUSION

In this paper, a high performance supervisory control was developed. Effective Energy management of batteries and super capacitors were created by the optimisation technique with higher level supervisory control. Voltage deviation and co-ordinated charging/discharging of ESS are the advantages from the proposed control compared with traditional methods. Based on SOC value of the ESS the supervisory control acts. Experimental tests for changing mode conditions have been carried out to validate the proposed control approach, showing smooth transitions between system-level modes.

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