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Enhancing Energy Extraction for a Multi-Resource Standalone Microgrid

Anuradha Tomar

***Abstract:** In a microgrid configuration integrated with different types of distributed energy resources (DERs), dedicated DC-DC converter stage ensures matching of source characteristics, to avoid power losses occurred due to the mismatching phenomena. However, in absence of proper coordinated control between DC bus and the inverter control, this additional energy extracted at dc bus may not be fully utilized. In this paper, an energy extraction maximization (EEM) control concept is proposed to increase the extraction and transfer of energy from DC bus to the load side through inverter control mechanism. Microgrid with multiple PV sources, fuel cell, battery and supercapacitor as DERs is considered for demonstration and EEM control is implemented on centralized inverter keeping configuration of other distributed energy sources intact. To illustrate the performance of proposed control, MATLAB/Simulink simulation has been carried out. Results obtained shows that proposed EEM control ensures the increased extraction of energy from dc bus and further a hardware implementation of the proposed concept is required to reach on some concrete results.*

***Keywords:** Battery energy storage (BES), Fuel cell, Maximum power point tracking (MPPT), inverter control, Microgrid, Photovoltaic (PV), Super capacitor, Renewable energy.*

I. INTRODUCTION

Despite of continuous efforts and many developments in the field of electrical power transmission and distribution system, many parts/rural areas of developing Nations are still not connected with main grid [1]. Isolated/standalone microgrids are good alternative as a sources of electrical energy in such remote areas where due to techno-economic reasons connectivity with National grid is not feasible. Harvesting green energy from Distributed energy resources (DERs) and thus forming small microgrid set-up is a promising concept [2].

Depending upon the geographical location and available DERs at the site of microgrid implementation, different configurations of microgrid are possible. Photovoltaic (PV) power is intermittent in nature [3] and not available in night hours, whereas wind energy is mainly available during hours [4].

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* Correspondence Author
Anuradha Tomar*, Department of Electrical Engineering, JSS Academy of Technical education, Noida, India. Email: Tomar.anuradha19@gmail.com

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Further, battery energy storage (BES) system could have been considered as a good option for continues and reliable source of energy, but its high maintenance cost limits its implementation capacity [5]. On the other side, Fuel cell (FC) is a low maintenance alternative of green energy, however it application is still limited by it high implementation cost [6]. Therefore, in order to design a microgrid of small village or remote area it is techno-economically beneficial to consider a combination of DERs which have characteristics balance and results in an overall economic operation of microgrid.

Microgrids can further be classified as AC, DC and hybrid AC/DC microgrid. A conventional DC microgrid may consist of PV panels, a fuel cell and a battery energy storage device connected to a common DC bus through DC to DC converters. A supercapacitor may also be connected directly to the DC bus as storage device for transient conditions. AC load is served by the DC bus using a DC to AC converter [7]-[8].

Design and control of microgrid configurations considering combination of with PVs, Fuel cells, BES, Supercapacitors etc. as a DERs, is available in literature [9]-[13]. DC-DC converters are generally used as an interface to connect various types of DERs to the common DC bus, with the objective to match the voltage levels of different energy sources. In case of PV systems, DC-DC converters are also responsible for MPPT operation of PV modules/arrays. When PV systems within same microgrid are located at different locations, Distributed MPPT is considered as an effective method to implement MPPT under mismatching scenarios. This additional extracted energy at DC bus may get lost, in absence of a coordinated control between DC bus voltage level and inverter control [14].

Further, integration of multiple distributed energy resources results in integration of sources with unsymmetrical/non-similar source characteristics. This results in the degradation of overall system performance, due to mismatching losses [15]. So, a control scheme needs to be designed in order to enhance the system performance. In conventional multi-sources microgrid configurations, constant voltage as a voltage magnitude reference is generally provided for the inverter control. This leads to less utilization or extraction of energy available at DC bus [16]; which further leads to the reduction in operational efficiency of the system [17]-[18].

In this paper, a standalone AC microgrid with DERs as multiple PVs, fuel cells, BES, and supercapacitor is considered and an Energy extraction maximization (EEM) control is proposed for inverter control.

The EEM control aims to provide a variable voltage reference for inverter control; based on the current and voltage levels at common DC bus which results in an increased energy transfer at inverter side and thus to the connected load.
Remainder of the paper is organized as follows: In section II, description of the considered microgrid configuration and operation is presented. Control strategy to maximize the energy utilization is illustrated in section III.
To verify the performance of proposed EEM control, considered configuration is simulated in MATLAB/Simulink environment and discussion on results is shared in section IV. Further, section V concludes the observations of proposed control.

II. SYSTEM CONFIGURATION & OPERATION

Fig. 1 depicts the considered microgrid configuration for demonstration of the proposed control strategy. Microgrid consist of PV, fuel cell, battery energy storage and supercapacitor as distributed source of energy. Broad specifications of sources are presented in Table 1 and capacity of the complete microgrid configuration is calculated as 42 kW.

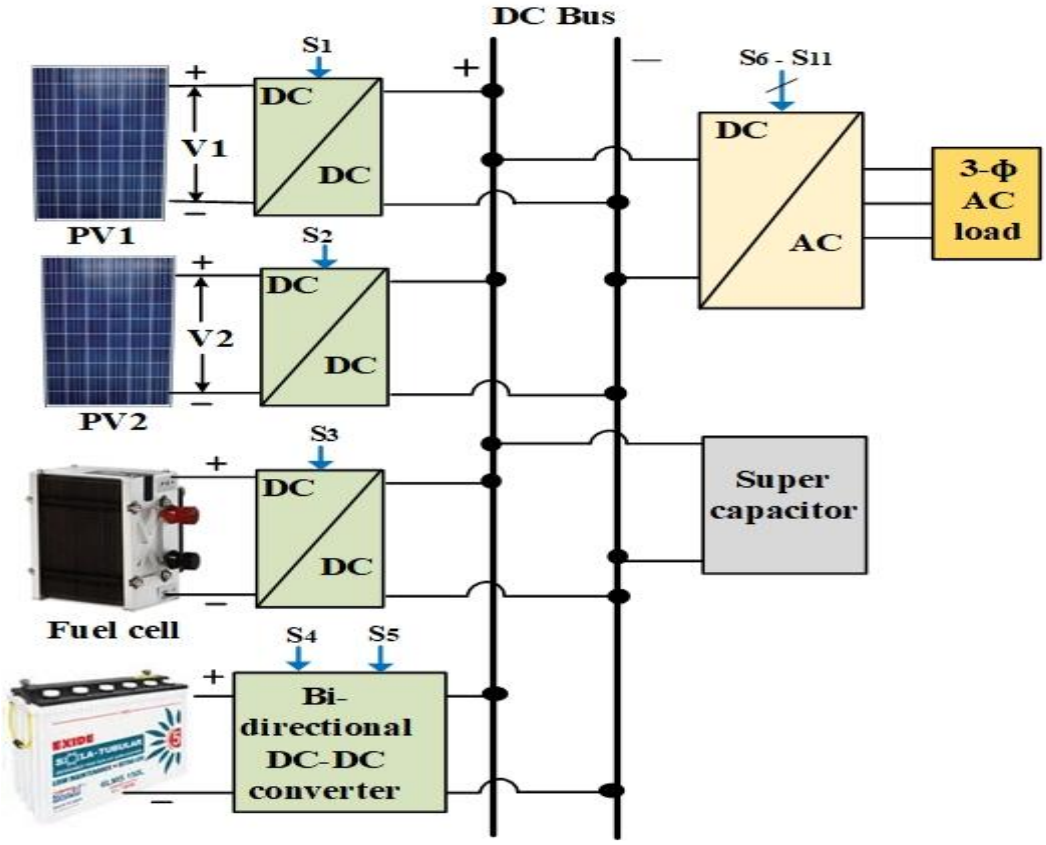

Figure 1 Configuration of considered standalone microgrid with multiple DERs

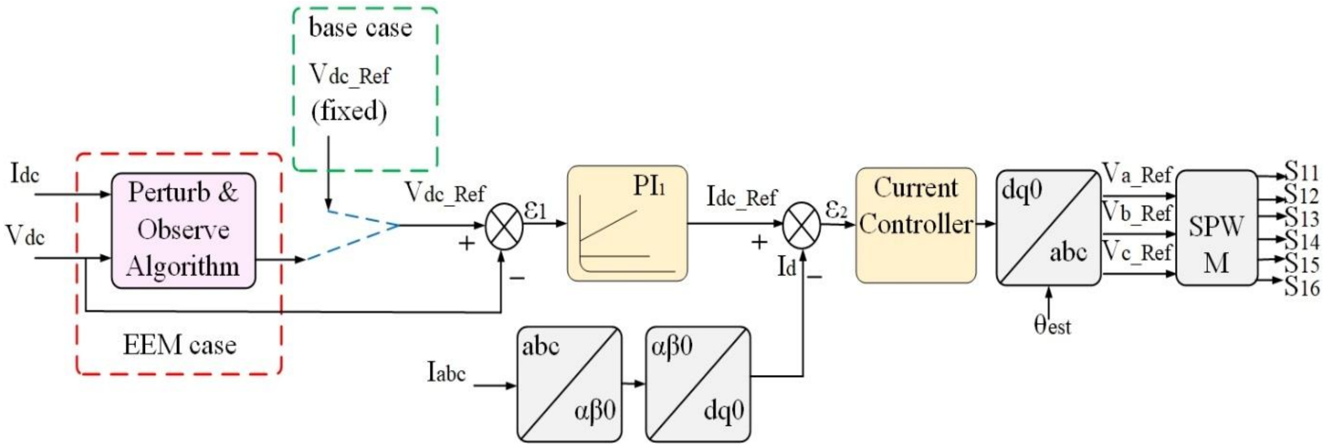

Figure 2 Proposed Energy extraction maximization control for 3-phase inverter control

Two PV systems (PV_1 and PV_2) are considered, which are assumed to be located at two different locations in order to

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depict the mismatching/shadowing phenomena in operation of PV system. Both PV resources PV_1 and PV_2 are equipped with dedicated DC-DC converter in order to ensure MPPT operation of their respective PV arrays. In multi resource microgrid structure, dedicated DC-DC converter helps in reducing the mismatching losses and enables PV system operation at MPPT, in order to extract maximum possible PV power [19]-[21].

Basic, yet effective Perturb & Observe (P&O) algorithm is chosen for MPPT control [22].

Proton exchange membrane (PEM) fuel cell power module with nominal power capacity of 10kW is considered and details on modelling of fuel cell may be further referred in [23]. PEM fuel cell is connected to the common dc bus through dedicated dc-dc converter which enables the voltage matching of fuel cell with the dc bus voltage by performing dc-dc converter boost action [24].

BES is modelled as per the details as investigated in [25]-[26] is hooked up to the dc bus by means of a bidirectional dc converter [27]. Bidirectional control of converter for BES is investigated to enable absorption and discharge of energy as per the availability of energy potential at dc bus, status of battery state of charge (SOC) %, load demand and power being generated by various DERs.

BES aims to maintain steady state equilibrium at dc bus while supercapacitor is helpful in maintaining the stable dc bus under transient conditions by enabling its fast charging and discharging; to balance the energy need of dc bus.

Table 1 Specification of various distributed energy sources

Distributed Source	Parameter	Rating
PV source @ STC (Two PV sources are connected in parallel)	P_{MPPT} ($P_{MPPT1} = P_{MPPT2}$)	7.88 kW
	V_{MPPT} ($V_{MPPT1} = V_{MPPT2}$)	273.5 V
	V_{OC} ($V_{OC1} = V_{OC2}$)	323 V
	I_{MPPT} ($I_{MPPT1} = I_{MPPT2}$)	28.8 A
	I_{SC} ($I_{SC1} = I_{SC2}$)	30.7 A
Fuel Cell	Power (peak)	12.5 kW
	Nominal power	10 kW
	Voltage PEM (proton exchange membrane) fuel cell power module	30-60 V
	Fuel cell DC/DC boost converter power	12.5 kW
Battery energy storage	Li-ion battery system	48 V, 40 Ah
Super capacitor (six 48.6v cells in series)	V_{SC}	291.6 V
	C_{SUPC}	5.6 F

III. PROPOSED ENERGY EXTRACTION MAXIMIZATION (EEM) CONCEPT

To address the limitations of multi-resources integration at common DC bus and further maximization of energy which is being extracted as AC side of the 3-phase inverter; the proposed EEM concept is presented in this section. Fig. 2, shows the control diagrams for generation of switching signals ($S_5 – S_{11}$) for 3-phase inverter control (Fig. 1).

Control of DC-DC converters, used at various stages in Fig. 1, is similar to the control configurations present in available literature, and therefore details of those control is not repeated here. In a two stage microgrid system i.e. DC-DC converter as first power converting stage and DC-AC converter as second converting stage, conventionally a fixed reference voltage magnitude is applied as reference for inverter control (considered as base case in Fig. 2). However, as discussed in the introduction section, application of fixed reference voltage magnitude limits the transfer of energy from DC bus to inverter side. Therefore, despite of the implementation of DC-DC converters at intermediate stage, to reduce the voltage mismatching and further increase in energy extraction, performance of such type of systems suffers from limited extraction of available energy DC bus.

As shown in Fig. 2, in the proposed EEM control, magnitude of V_{REF} is calculated based on the level of voltage and current at DC bus and further, applying the concept of Perturb & Observe (P&O) MPPT algorithm [19]-[21]. This approach helps the system control to vary the DC bus voltage potential such that to maximize the energy extraction. As a result, an increase in inverter output power is expected. Proposed control have no implementation limitations, as P&O algorithm is well known in literature. Further, EEM control does not require any additional cost, as measurement of V_{dc}, V_{abc}, I_{abc} are part of measurement for conventional control architecture also. Hence, proposed control does not leads to added complexity or implementation cost as compared to the conventional system control and results in increased energy yield.

IV. SIMULATION RESULTS

A microgrid configuration with various types of DERs PV, fuel cell, BES and supercapacitor, as shown in Fig. 1 is simulated in MATLAB/Simulink environment and results are illustrated in this section.

Results obtained with proposed control are further compared with base case system (as shown in Fig. 2), in order to understand the effectiveness of proposed control. A base case system with same number of components and ratings but with different inverter control is considered. Inverter control considered for base case system is similar to the conventional control of microgrid with multiple DERs and it is depicted in Fig. 2 with fixed reference voltage.

As mentioned earlier, PV sources 1 and 2 are considered in distributed manner and are located at two different locations, therefore irradiance is considered as 800 W/m^2 and 600 W/m^2 for PV_1 and PV_2 respectively to depict the mismatching scenario. The considered irradiation variation help to analyze the MPPT performance of the proposed control, when considerable mismatch is their between two PV resources. Further, irradiance is considered to be constant throughout the simulation for both types of considered PV systems. Fig. 3 and 4, shows a comparison of base case and proposed system for the power being extracted at DC bus and AC power being transferred to the load respectively. As shown in Fig. 4, AC power which is being ultimately transferred to the AC load is approximately 38 kW in proposed EEM case as compared to 16 kW AC power being extracted for the base case.

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This enhanced energy extraction is a result of proposed EEM concept, which adjust the DC bus voltage level such that super-capacitor contributes more in terms of energy being extracted at DC bus and thus enables enhanced energy transfer from DC bus to the inverter side by incorporating coordinated control at inverter side. Performance of the base case system is impacted due to the presence of a fixed reference voltage at inverter control, which limit the amount of energy that could be transferred through DC bus to the AC side of the inverter. This phenomena accelerates with the increase in mismatching scenario among the various connected DERs.

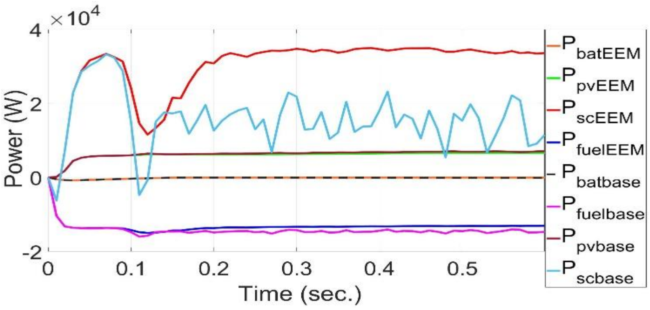

Figure 3 Variation in power at DC bus with time

Fig. 5 depicts the voltage value status for the proposed system and base case. As seen in Fig. 6, reference DC bus voltage (V_{refEEM}) for the EEM control keeps on changing within a bounded limits, to enhance the energy extraction. However, as shown in Fig. 8, voltage reference for base case ($V_{refbase}$) remains constant throughout the simulation. V_{dcbase} and V_{dcEEM} are the measured DC bus voltage for base case and EEM case respectively.

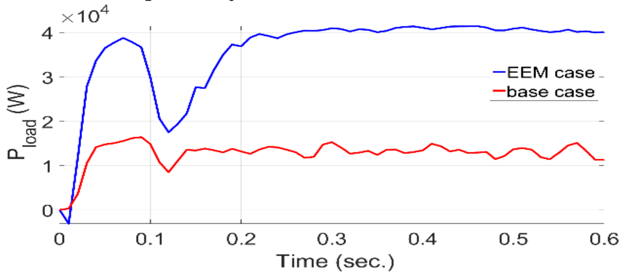

Figure 4 Variation in extracted power as an output of inverter with time

From Fig. 5 it can be observed that deviation in measured DC bus voltage is within ±3% for the both the systems. However, a more precise control could be obtained to follow the variation in reference voltage signal.

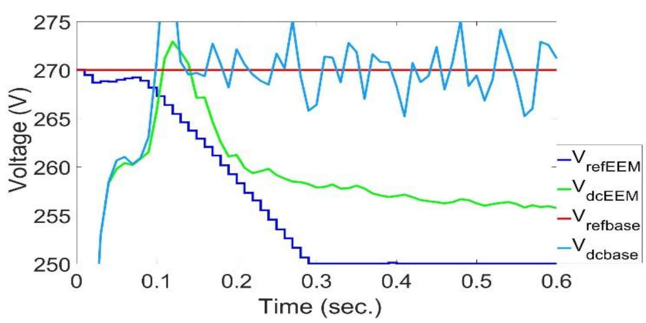

Figure 5 Variation DC bus reference and measured values for both the considered cases

Further, Fig. 6 and 7 represents the power-voltage characteristics for the PV source 1 and 2. It is evident from Fig. 4 and Fig. 6, that both PV sources are being operated at their respective MPPT points. Therefore, it can be concluded that EEM control does not have any adverse impact on MPPT operation of PV sources.

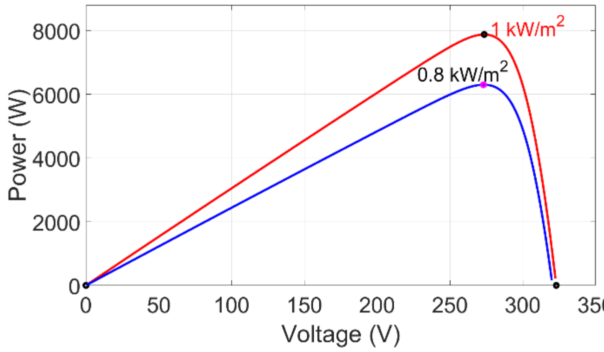

Figure 6 P-V characteristics for PV sources1

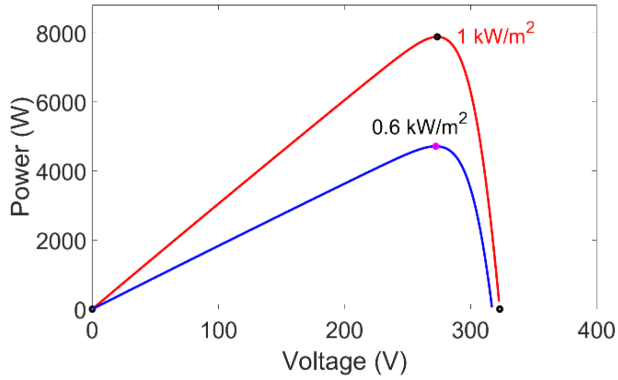

Figure 7 P-V characteristics for PV sources 2

V. CONCLUSION

In this paper, a 3-phase inverter control is demonstrated for a multi-resource standalone microgrid with objective to increase the extraction energy from available DERs. It is observed that inverter control based on fixed reference DC bus voltage limits the amount of transferable energy from Dc bus to AC side of inverter in case of conventional inverter control.

In the proposed EEM concept, inverter reference DC bus voltage adapts a value based on the status of energy available DC bus and thus results in an increased extraction of available DC bus energy. The results obtained through simulation in MATLAB/Simulink environment verifies the performance of proposed control.

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AUTHOR PROFILE

Dr. Anuradha Tomar, is currently working as Postdoc researcher in EES Group, Eindhoven University. She is also associated as an Associate Professor with the Electrical Engineering Department at JSS Academy of Technical Education, Noida, India. She received her B.E degree in Electronics Instrumentation & Control Engineering with "Honours" from University of Rajasthan in 2007. She had completed her M.Tech, in Power System with "Honours" from National Institute of Technology, H.P in the year 2009. She received her Ph.D in Electrical Engineering, from Indian Institute of Technology Delhi. She has an academic and research of more than 10 years in Engineering Institutions affiliated with GGSIP University, AKTU University. She is Senior member of IEEE, Life member of ISTE, IETE, IEI, IAENG. Her areas of interest are Photovoltaic system, Microgrid, Energy conservation and Automation. She has published Research/review papers in reputed International journals IEEE, National Journals and International Conferences.

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