Power Flow Analyses of a Standalone 5-Buses IEEE DC Microgrid for Arid Saharian Zone (South of Algeria)

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Abstract. Fast growing of Algerian population and their non-uniform distribution caused electrical perturbance in grid lines and distribution stations, such as interruptions, voltage/frequency drop, poor power quality, short circuits, and high voltage phenomena. In addition, hard terrains and weather conditions are most impediments in linking Saharian citizens with electricity. For that reason, microgrid networks can be an efficient solution to solve this problem using renewable energies REs due to the high solar potential, and storage system ESS. In this study, we present a prototype of a DC Microgrid destined for residential-agricultural investors in the south of Algeria-Adrar zone. These farms are interconnected through cables to share energy from/to the other farms, which its internal sub-networks to cover its demand independently, while the total demand is covered by a backup unit includes diesel generator and batteries in emergency cases. Thus, an energy management centre EMC controls the functioning of the whole system and managing the shared energy inside the Microgrid. The Microgrid is run in ETAP software, where static and dynamic regimes are studied. From power flow analyses, we can observe that the DC network operates efficiently under stable nodal buses that reflect the availability of the power supply. Hence, the design concept is verified through test scenarios to demonstrate the capability of the proposed microgrid.

Keywords: DC microgrid · Renewable energies REs · Energy management system EMS · Power flow analyses · Standalone system

1 Introduction

This document presents a DC Microgrid structure for feeding a group of agricultural farms in the big south of Algeria [1]. In hand, farms are isolated form the main AC grid and in other hand, the agricultural farms contain residential homes equipped with the needed essential appliance for their works and activities. The principal activities in the

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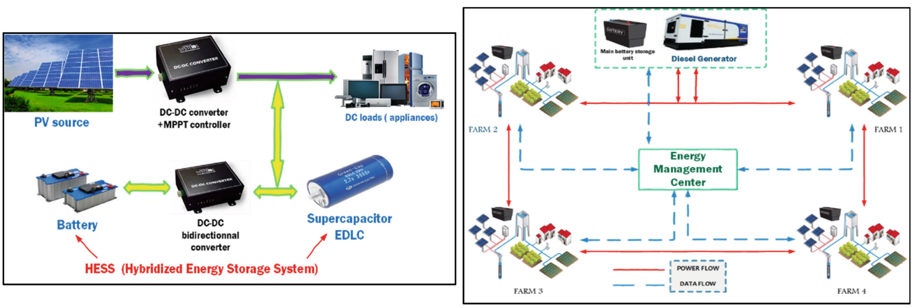
south Saharian sites focus on water extraction from the ground to irrigate crops, and for daily uses. The DC Microgrid network aims essentially to supply the needed energy continuously and efficiently. The proposed structure regroups four agricultural farms through power links to achieve Load Flow LF and power balance, and data link to exchange sub-networks parameters needed for management control center [2]. The main objectives of this work are:

- Insuring self-sufficiency and continuous electrical supply for the interconnected farms 24 h, and during emergency and critical periods through storage system HESS and the backup diesel genset [3].
- Facilitate agricultural activities of farmers in remote and isolated sites [4].
- Safe renewable electrical supply (DC) as clean, environmentally and friendly [5].
- Stable power balancing between the sub-networks through different LF load flow methods.
- In literature, various methods are used to size such systems including REs and storage devices as optimization methods and genetic algorithm [6].

2 Description of the Proposed DC Microgrid Network

The hybrid-studied network regroups four farms through data and power links with a common backup unit as viewed in Fig. 1. Each separated farm contains PV and batteries for feeding their appropriate load demand [7, 8], where the four farms have a common backup storage system and a diesel source for the emergency cases. The management center insure an optimal load flow for the global network through the measured parameters of each device such as dc bus voltage, frequency, currents, powers, SOC (state of charge) of the storage system, sun irradiations, temperature, losses in buses, branches and cables, and the protective devices state such as fuses and circuit breakers [2, 9, 10].



(a) (b)

Fig. 1. Proposed DC Microgrid structure: a-Full circuit, b-sub-network circuit of farms

The treated system links four agricultural farms in the Matlab structure, while a composite sub-network in ETAP software represents it. Hence, each sub-network has its own small-scale renewable system to supply its need of energy, while the backup unit copes with the global demand of the whole system following a specified load schedule and management policy. The DC-MG is supplied mainly via renewable energies and autonomy storage devices resulting in a high renewable fraction and reducing the use of traditional sources or the grid utility, and minimizing the negative impacts of the environment. In contrast, the big drawback of such systems is the initial coast, which includes the components, the installation, the transport, and the maintenance. For that reason, this work aims to reach the following objectives:

- Model, simulate and control the proposed DC-MG network in Matlab/Etap software.
- Study the static and dynamic regimes of the DC-MG using Etap and Matlab software respectively.
- Evaluate the obtained results under real-variable parameters such as solar irradiation, wind speed, and temperature.
- Test the viability of the proposed energy management policy to manage the shared energy with respect to the boundaries of the DERs, the storage devices, and based on a specified load schedule.

2.1 Modelling of the PV Source

The PV source model can be represented by an equivalent circuit, where an ideal current source represents the photovoltaic, series resistance R_S for voltage region operation and parallel resistance R_P for current source region operation respectively [11]. In addition, a pay-bass diode can be added at the output of the PV source to protect the PV against reversed currents. Hence, this equivalent source take into account series and parallel connection of multiple arrays to increase the output generation of I_{PV} and V_{PV}. The mathematical model of the PV can be represented by the following expressions in Eqs. (1–3), where the generation at the maximum point MPP is [12, 13]:

$$\begin{cases} \boldsymbol{I_{pv}} = (\boldsymbol{I_{pv,N}} + \boldsymbol{K_I}.\Delta_{\boldsymbol{T}}).\frac{\boldsymbol{G}}{\boldsymbol{G_n}} \\ \boldsymbol{P_{pv-MPPT}} = \boldsymbol{V_{MPPT}}.\boldsymbol{I_{MPPT}} \end{cases} \quad (1)$$

The PV array parameters are open-circuit voltage (Voc), short-circuit current (Isc), maximum point voltage (V_{MPP}), maximum point current (I_{MPP}), open-circuit voltage/temperature coefficient (K_V), short circuit current/temperature coefficient (K_I). This information is provided with reference to the nominal condition of temperature and solar irradiation (STC). In addition, The I/V and V/P curves represent the current, voltage and power of the PV at different irradiation (W/m^2). Thus, three main operating points can be distinguished defined by [V_{PV}, I_{PV}], which are the open circuit point [V_{OC}, 0], short-circuit point [I_{SC}, 0], and maximum power point [V_{MPP}, I_{MPP}]. Various MPPT technics can be used to extract the PV power including simple, genetic and developed methods as mentioned in [14].

2.2 Modelling of the Diesel Source

The diesel genset consists of a diesel engine coupled to a synchronous generator. A speed controller maintains the alternating current frequency at the output, and the regulator works by adjusting the fuel flow in order to keep the engine speed and generator speed constant. However, the machine functions as a synchronous compensator and provides reactive energy [15]. Hence, the total fuel cost (Fc) at time and the generation limits of the generator set can be represented by the following expressions in Eqs. (4) and (5) respectively [16]:

$$\begin{cases} F_C = \int_0^{\tau} (aP^2(t) + bP(t) + c)d_t \\ P_{Gen}^{min} \le P_{Gen} \le P_{Gen}^{max} \end{cases} \tag{2}$$

2.3 Modelling of the Yrid Storage System Hess

The hybrid storage system includes battery and Electric Double Layer Capacitors EDLC supercapacitor devices, connected in battery semi-active topology. The following Eq. (3) defines the output voltages of the storage devices [13]:

$$\begin{cases} V_{battery} = E = E_0 - K\frac{Q}{Q-i_t}.i_t - R_b.i_t + A_b.\exp(-B.i_t) - K\frac{Q}{Q-i_t}.i^* \\ V_{sc} = \frac{Q_T}{C_T} - R_{sc}.i_{sc} \end{cases} \tag{3}$$

Where E_0 is the battery constant voltage (V), K is the polarization constant (V/Ah), Q is the battery capacity (Ah), i* is the filtered battery current (A), it is the actual battery charge (Ah), A_b is the exponential zone amplitude (V), B is the exponential zone time constant inverse Ah^{-1} and Rb is the battery internal resistance (Ω). Q_T is the total electric charge (C), R_{SC} is the super capacitor module resistance (Ω) and i_{SC} is the supercapacitor module current (A).

2.4 Modelling of Power Onerters

The power converter are used to transfer the generated power of the distributed energy sources to the appropriate loads through a common dc link or bus. In this work, only non-isolated dc-dc converters are used such as boost, and buck-boost converters. The boost converter is connected with the PV to extract its maximum power, where the switching device of the converter is controlled via the MPPT-PWM signals. The HESS consist of a bidirectional converter BDC connected with the battery to control the charge-discharge cycles, the narrow scope of SOC, and the bus voltage stable or nearly stable. Equation (4) is used to linearize the above state-space equations of the Boost converter (5), where X is the steady-state component and D is the steady state or DC component duty-ratio. Hence, the state space averaged model of the bidirectional converter in equilibrium is shown in Eq. (6) [17].

$$\dot{X} = \left[\overline{D}A_{on} + (1 - \overline{D})A_{off}\right]X + \left[\overline{D}B_{on} + (1 - \overline{D})B_{on}\right]Y \tag{4}$$

$$\left\{ \begin{bmatrix} \dot{i}_L \\ V_c \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1-D}{L} \\ \frac{1-D}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{V_c}{L} \\ -\frac{i_L}{C} \end{bmatrix} d; \right. \tag{5}$$

$$\left\{ \begin{array}{l} \dot{X} = AX + BY \\ 0 = \begin{bmatrix} -\frac{R_L}{L} & \frac{D}{L} & -\frac{1}{L} \\ -\frac{D}{C_H} & -\frac{1}{R_{in}.C_H} & 0 \\ \frac{1}{C_L} & 0 & -\frac{1}{R_{Load}.C_L} \end{bmatrix} \begin{bmatrix} i_L \\ V_L \\ V_H \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & \frac{1}{R_{in}.C_H} \\ \frac{1}{R_{Load}.C_L} & 0 \end{bmatrix} \begin{bmatrix} V_L \\ V_H \end{bmatrix} \end{array} \right. \tag{6}$$

R_L is the internal resistance of the inductor, R_{in} is the internal resistance of the input source, R_{load} represents the load resistance, equivalent to V_{load}^2/P_{load}, C_H and C_L are high and low side capacitances respectively, V_L and V_H are low and high side voltages.

The studied DC Microgrid is located in the big southern of Algeria (BECHAR – ADRAR), where: latitude = 27.9716°, longitude = 0.1870°. The full structure of the studied network in Matlab simulink aims to analyze static and dynamic states of the operating variables and to test the viability and efficiency of the management strategies. ETAP software is specifically designed for power system simulation, which facilitate system analysis such as steady state, security assessment, state estimation, optimal power flow, DC/AC load flow. After this description, tests of performance of the selected topology and the efficiency of the network can be achieved through next analysis (Table 1):

Table 1. Matlab and ETAP softwares analysis.

Matlab analysis:	ETAP analysis:
DC/AC load Flow analysis. DC/AC short-Circuit analysis. Energy Management (flowcharts and algorithms). Charge-discharge of storage devices. Transient and permanent analysis	DC/AC Load Flow analysis. DC/AC Short-Circuit analysis. Battery Discharge sizing. Optimal Power Flow analysis. Motor acceleration analysis. Harmonic analysis. Transient stability analysis. Protective device coordination. Switching Sequence Management

3 Results and Discussion

This section represents initial results and discuss it to improve model viability and operating conditions under different scenarios and perturbance. Results of the two softwares are discussed separately.

3.1 ETAP Software Results

Load flow analyses are achieved on ETAP software in order to achieve the following purposes:

1- Off-line method of calculating the voltage and angle at the bus.
2- Solve the set of nonlinear power balance equations.
3- Load flow is root-finding problem, where this problem is converted to optimization problem.

Our five buses DC microgrid shown in Fig. 2 is modelled using ETAP software, where dc load flow LF analysis were made. Thus, 10 load flow scenarios are selected, where the load demand is supplied by the combination between the used DERs of the system, which are PV, local batteries, main storage, and diesel generator. In each case, load flow results include bus voltages, injected and consumed powers; global losses and iteration number are plotted and discussed. Table 2 resumes initial parameters of LF analysis. Hence, the DC loads were supplied via its DC-DC converter to reduce the bus voltage of 270.3 V_{DC} to 24 $V_{DC,}$ which is adaptive with the common DC appliances, and with the used MPPT and PWM regulator in order to control and supply safe DC energy (Table 3).

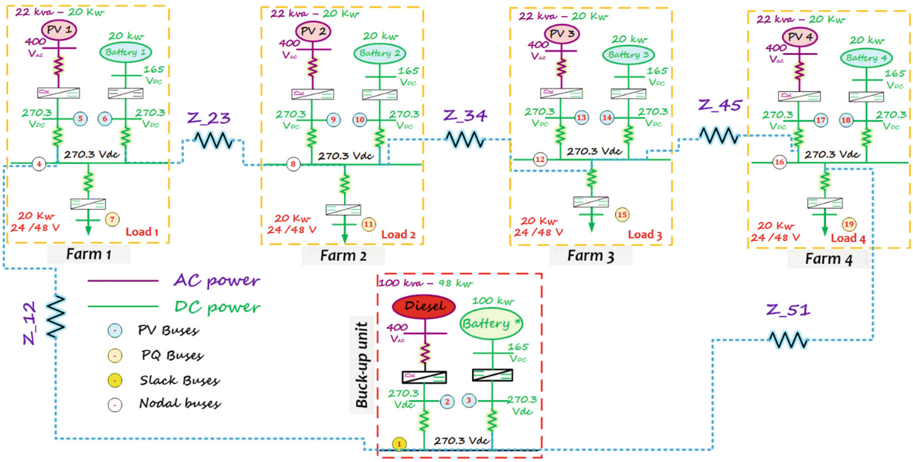


Fig. 2. Proposed DC Microgrid structure: a-Full circuit, b-sub-network circuit of farms

After running load flow analyses of the five buses DC-MG using 10 proposed management scenarios, the energy balance and the losses are summarized in the next table.

Table 2. Load flow line and bus data

	Bus data (pu)		Line data				
Bus No.	Bus type	Initial V_{BUS}	From	To	R_{BUS}	L_{BUS}	Distance (m)
1	SLACK	1	1	4	.05098	.00014	100
2	PV	1	4	8	.05098	.00014	120
3	PV	1	8	12	.05098	.00014	90
4	PV	1	12	16	.05098	.00014	50
5	PV	1	16	1	.05098	.00014	135

Table 3. Load flow results

No.	Scenarios	Parameters					
		Production (pu)	Consumption (pu)	Losses (pu)	Iterations	State	No. of power converter
1	PV only	1.0205	1	0.0205	1	Normal	8/14
2	Local batteries only	1.0413		0.0413		Normal	8/14
3	Diesel only	1.0208		0.0208		Emergency	5/14
4	Main storage only	1.0311		0.0311		Emergency	5/14
5	PV + local batteries	1.0354		0.0354		Critical	12/14
6	PV + Diesel	1.0205		0.0205		Critical	9/14
7	PV + Main storage	1.0234		0.0234		Critical	9/14
8	Diesel + Main storage	1.0311		0.0311		Emergency	6/14
9	Diesel + Local batteries	1.04		0.04		Critical	9/14
10	Main storage + Local batteries	1.0413		0.0413		Critical	9/14

The total load demand of the whole network is about 80 (Kw)–1 (p.u). As seen in Fig. 3, in different scenarios, the operating voltages of the 5 buses were within its limits with a minimum of 0.9997 p.u, which reflects the stability of the power balance, where the totality of the load demand is supplied sufficiently and efficiently by the distributed energy resources DERs under different scenarios. In addition, very few losses was measured during LF analyses, which were varying [1.64–3.3] (Kw) due to the studied sizes of the dc cables with transport distances. The next figure shows the nodal buses of each scenario, where the energy balance were stable under the used management scenarios, except in the 3 emergency cases.

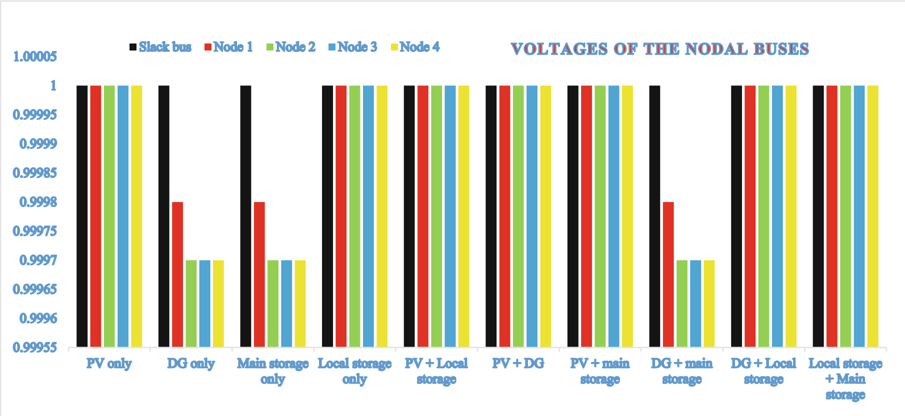


Fig. 3. ETAP results of the nodal buses of the DC-MG system

In these cases, the interconnected farms have been supplied by the backup unit energy in order to cope with their lack of energy. In contrast, and during the rest scenarios, the sub-networks have supplied the loads demand sufficiently and efficiently through the generated energies of the DERs of the studied system.

4 Conclusion

In this brief paper, a dc microgrid network is studied. The microgrid module are presented through mathematical and equivalent circuits of DER and power converters, in addition to management strategies structures. The dc microgrid is tested using Matlab simulink and ETAP softwares in order to study transient and steady state parameters respectively. Thus, load flow tests are carried by ETAP software, where branches, cables, buses, and power flow results are plotted and discussed. In addition, other test are achieved using Matlab simulink, where the PV power conversion chain, storage devices are tested and main parameters are figured and discussed. Therefore, this model is under construction, where backup generator and the energy management of the network are not studied and modelled yet. As a future perspective, next work focus on connecting such sub-systems as a DC Microgrid and modelling the backup unit including diesel generator for the whole microgrid.

References

1. Hatziargyriou, N. (ed.): Microgrids: Architectures and Control. Wiley, Hoboken (2014)
2. Chalise, S.: Power management of remote microgrids considering battery lifetime (2016)
3. Meegahapola, L.G., et al.: Microgrids of commercial buildings: strategies to manage mode transfer from grid connected to islanded mode. IEEE Trans. Sustain. Energy **5**(4), 1337–1347 (2014)

4. Manas, M.: Renewable energy management through microgrid central controller design: An approach to integrate solar, wind and biomass with battery. Energy Reports **1**, 156–163 (2015)
5. Yin, C., et al.: Energy management of DC microgrid based on photovoltaic combined with diesel generator and supercapacitor. Energy Convers. Manag. **132**, 14–27 (2017)
6. Kumar, A., Biswas, A.: Techno-economic optimization of a stand-alone photovoltaic-battery renewable energy system for low load factor situation-a comparison between optimization algorithms. Int. J. Eng.-Trans. A: Basics **30**(10), 1555–1564 (2017)
7. Mahmood, et al.: A power management strategy for PV/battery hybrid systems in islanded microgrids. IEEE J. Emerg. Sel. Topics Power Electron. **2**(4), 870–882 (2014)
8. Diaz, et al.: Intelligent distributed generation and storage units for DC microgrids—a new concept on cooperative control without communications beyond droop control. IEEE Trans. Smart Grid **5**(5), 2476–2485 (2014)
9. Bhattacharjee, A.: Decentralized power management in microgrids (2014)
10. Nunna, H.K., et al.: Multiagent-based distributed-energy-resource management for intelligent microgrids. IEEE Trans. Ind. Electron. **60**(4), 1678–1687 (2013)
11. Pan, L.: Analysis of photovoltaic module resistance characteristics, pp. 1369–1376 (2013)
12. Brahmi, N., et al.: Optimum sizing algorithm for an off grid plant considering renewable potentials and load profile. Int. J. Renew. Energy Dev. **6**(3), 213 (2017)
13. Rivera, O., et al.: Hardware in loop of a generalized predictive controller for a micro grid DC system of renewable energy sources. Int. J. Eng. **31**(8), 1215–1221 (2018)
14. Boutabba, T., et al.: A new implementation of maximum power point tracking based on fuzzy logic algorithm for solar photovoltaic system. Int. J. Eng.-Trans. A: Basics **31**(4), 580–587 (2018)
15. Feddaoui, O.: Contribution à l'Etude des Systèmes Hybrides de Génération: Application aux Energies Renouvelables. Doctoral dissertation, University of Souk Ahras (2014)
16. Rouholamini, M., Mohammadian, M.: Grid-price-dependent energy management of a building supplied by a multisource system integrated with hydrogen. Int. J. Eng.-Trans. A: Basics **29**(1), 40–49 (2016)
17. Ghazanfari, A., et al.: Active power management of multihybrid fuel cell/supercapacitor power conversion system in a medium voltage microgrid. IEEE Trans. Smart Grid **3**(4), 1903–1910 (2012)