Systèmes d'Énergie Électrique dans leurs Dimensions Sociétales
GDR 2994

GT
Micro-réseaux

Journée Scientifique Nationale
9 Juillet 2018

Université de Technologie de Compiègne
Centre d'Innovation, avenue de Landshut, 60200 Compiègne

Invités : industriels et chercheurs

Session Plénière

Sessions parallèles

Synthèse des travaux

Systèmes d'Énergie Électrique dans leurs Dimensions Sociétales - GdR 2994

GT Micro-réseaux JSN - 2018

9 juillet 2018, Compiègne, France

UNIVERSITE DE TECHNOLOGIE DE COMPIEGNE

Laboratoire AVENUES EA 7284

Journée Scientifique Nationale Micro-réseaux – 9 juillet 2018

UNIVERSITE DE TECHNOLOGIE DE COMPIEGNE, Centre d'Innovation, av. de Landshut, Compiègne, France

Organisée par le GT Micro-réseaux, groupe thématique du GDR SEEDS, la 2e édition de la Journée Scientifique Nationale (JSN) se déroulera à Compiègne le 9 juillet 2018. Cette manifestation permet aux chercheurs, doctorants et industriels de présenter leurs travaux et d'échanger sur la thématique des micro-réseaux.

L'objectif de la JSN Micro-réseaux 2018 est de présenter différents développements de micro-réseaux, tant théorique qu'applicatif, et qui offrent des informations sur leurs contrôles et les applications possibles. Il s'agit des synthèses concernant les travaux autour des micro-réseaux d'une équipe (laboratoire), des travaux en cours, des projets en cours, de nouvelles plateformes technologiques, des partenariats industriels/institutionnel, …

Les sujets d'intérêt relèvent de la communauté du GT Micro-réseaux au sens large, mais peuvent aussi traiter de sujets transversaux ou d'exemples applicatifs :

- Modélisation, contrôle et gestion des micro-réseaux ;
- Contrôleurs pour micro-réseaux AC et DC ;
- Qualité de l'énergie pour micro-réseaux ;
- Convertisseurs statiques pour micro-réseaux (topologies, efficacité, performances ...) ;
- Systèmes de stockage d'énergie pour micro-réseaux ;
- Gestion d'énergie pour les micro-réseaux (planification optimale, délestage de charge, optimisation en temps réel, prise en compte des incertitudes ...) ;
- Démonstrations, applications et projets pilotes.

Conférenciers invités

- Thierry DHAINAUT, ENEDIS Picardie
- Serge PELISIER IFSTTAT-LTE), Christophe FORGEZ (ROBERVAL) : animateurs du GT Stockage électrochimique de l'énergie électrique
- Benoit DELINCHANT (G2Elab), Salvy BOURGUET (IREENA) : animateurs du GT Optimisation des systèmes complexes et hétérogènes

Dates à retenir :

Soumission d'un résumé (2 pages) avant le **10 juin 2018** à l'adresse manuela.sechilariu@utc.fr

Délibérations concernant les exposés et les posters : le **25 juin 2018**

Inscriptions gratuites mais obligatoires avant le **15 juin 2018** à l'adresse

https://www.eventbrite.com/e/gt-micro-reseaux-jsn-2018-tickets-44477017958
mot de passe : GDRSEEDSGTMICRORESEAUX

Programme définitif : le **27 juin 2018**

Comités du programme

Conférence Chair

- Manuela SECHILARIU, AVENUES, Université de Technologie de Compiègne

Comité scientifique

- Robin ROCHE, FEMTO-ST FCLab, Université de Technologie de Belfort-Montbéliard
- Florence OSSART, GeePs, Sorbonne Université
- Mamadou Baïlo CAMARA, GREAH, Université Le Havre Normandie
- Manuela SECHILARIU, AVENUES, Université de Technologie de Compiègne
- Fabrice LOCMENT, AVENUES, Université de Technologie de Compiègne

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Programme

9h00 : Accueil, café et visite de la plateforme STELLA[1]

Session plénière (amphithéâtre Centre d'Innovation)

10h00 : Ouverture de la journée, **Manuela SECHILARIU** (AVENUES-UTC), responsable du GT Micro-réseaux

10h10 : Le réseau public d'électricité en mutation pour faciliter la transition énergétique,
Thierry DHAINAUT, ENEDIS Picardie Directeur adjoint ingénierie

11h00 : GT Optimisation des systèmes complexes et hétérogènes,
Benoît DELINCHANT (G2Elab) et **Salvy BOURGUET** (IREENA)

11h30 : GT Stockage électrochimique de l'énergie électrique,
Serge PELISSIER (IFSTTAR) et **Christophe FORGEZ** (ROBERVAL-UTC)

12h00 : Déjeuner (buffet convivial) et visite de la plateforme STELLA

Sessions parallèles (salles Centre d'Innovation)

13h30 : Session 1, chairman **Robin ROCHE**, 6 présentations orales

13h20 : Session 2, chairman **Florence OSSART**, 7 présentations orales

15h30 : Pause-café et visite de la plateforme STELLA

Session plénière (amphithéâtre Centre d'Innovation)

16h00 : Synthèse des travaux, chairmans **Robin ROCHE** et **Florence OSSART**

16h20 : Bilan du GT Micro-réseaux et nouvelle organisation, **Manuela SECHILARIU**

17h00 : Fin de la journée

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[1] Plateforme technologique STELLA : Micro-réseau dédié aux stations de recharge des véhicules électriques

Session plénière (amphithéâtre Centre d'Innovation)

10h10 : Le réseau public d'électricité en mutation pour faciliter la transition énergétique, Thierry DHAINAUT, ENEDIS Picardie Directeur adjoint ingénierie

- L'exposé portera sur les défis que doivent relever les réseaux électriques face à l'intégration des énergies renouvelables et des véhicules électriques.
- Questions, discussions

11h00 : GT Optimisation des systèmes complexes et hétérogènes, Benoît DELINCHANT (G2Elab) et Salvy BOURGUET (IREENA)

- Les systèmes du génie électrique font appel à des éléments de plus en plus complexes et de natures multi-physiques qui nécessitent dès la conception la prise en compte de multiples critères à la fois techniques (performances, encombrement, rendements énergétiques), économiques (coûts d'investissement, d'exploitation, de maintenance, ...) voire sociologiques et environnementaux. La prise en compte des couplages et des interactions entre composants d'un même système et avec son environnement, est nécessaire à la mise en œuvre de processus de conception et/ou de pilotage, conduisant à l'optimisation de la performance globale du système. Les travaux menés dans le GT doivent contribuer à intégrer aux processus d'aide à la décision (conception/pilotage) une modélisation des principaux phénomènes qui influencent les critères de performance du système et à apporter des méthodes et des outils pour l'aide à la formulation, à la résolution, et à l'analyse de ces problèmes. Des travaux relatifs à la conception et gestion énergétique des bâtiments seront utilisés comme support illustrant ce qui peut être étudié dans notre GT Optimisation de Systèmes Complexes et Hétérogènes. Nous verrons plus particulièrement les méthodes de modélisation au niveau système, adaptées au mieux aux outils de résolution et d'analyse tels que les méthodes d'optimisation, que nous comparerons en terme de performances.
- Questions, discussions

11h30 : GT Stockage électrochimique, Serge PELISSIER (IFSTTAR) et Christophe FORGEZ (ROBERVAL-UTC)

- La transition énergétique indispensable pour réduire la dépendance aux énergies carbonées nécessite de développer des solutions de stockage direct de l'énergie électrique à base de batteries et de super-condensateurs, ou indirect avec des systèmes à pile à combustible. Les applications sont stationnaires (énergie renouvelable, réseaux intelligents, …), embarquées (transports, outillages,…) ou associant les deux utilisations (Vehicle-to-Grid V2G). De nombreux laboratoires de la communauté SEEDS abordent cette thématique du stockage. Un des objectifs de ce GT est de permettre une interconnaissance des acteurs afin de mieux articuler leur complémentarité en compétences et en plateformes expérimentales. Il favorise les échanges avec les autres acteurs de la recherche (autres GT SEEDS, autres GDR ou autres Réseaux) ou les industriels en ayant un rôle de guichet unique. Les besoins de recherche portent sur les systèmes de management et de surveillance de ces composants (état de charge, état de santé, équilibrage, …), sur la connaissance des conditions d'utilisation des différentes applications, sur les lois de vieillissement en usage réel. Une difficulté particulière vient de la diversité des applications et de la non-maturité de certaines technologies en évolution rapide. Il est alors important de construire des méthodologies qui permettront de mettre à jour les résultats pour les applications et les technologies futures. Actuellement les technologies de batteries lithium-ion concentrent l'essentielle des recherches grâce à leurs très bonnes performances dans la plupart des applications. Par contre ces technologies nécessitent des conditions de surveillance bien particulières. En ce qui concerne les problématiques "stockage" dans les réseaux, il est utile de distinguer au moins trois types de configurations : réseaux embarqués, micro-réseaux et réseaux HT. Les questions de recherche soulevées par ces applications portent sur les conditions d'usages spécifiques à chacune et leurs incidences sur le vieillissement des batteries. L'utilisation de batteries de seconde vie issues de l'électromobilité est aussi une thématique nouvelle. Il faut être en mesure d'évaluer avec précision et rapidité les caractéristiques "dégradées" afin de redimensionner les systèmes ou de reconfigurer les assemblages de cellules. Cette intervention permettra de faire le point sur les potentielles interactions entre les GT "stockage" et "micro-réseaux".

- Questions, discussions

Sessions parallèles[1] (salles Centre d'Innovation)

13h30 : Session 1, chairman Robin ROCHE (FEMTO-FClab UTBM)

1. Impacts of SCs on battery lifetime in HESS on DC Microgrids in BiPV, M. Gaetani-Liseo C. Alonso, B. Jammes, LAAS-CNRS, Université Toulouse III - Paul Sabatier
2. Battery voltage increase based on DC/DC converters in parallel association, JP. Sawicki, P. Petit, F. Maufay, M. Aillerie, LMOPS-EA 4423, Université de Lorraine et CentraleSupelec
3. Variable speed diesel -PV power generation for micro micro-grid applications, M.M.G. Lawan, J. Raharijaona, M.B. Camara, B. Dakyo, GREAH Université du Havre-Normandie
4. Impacts of demand side management strategies application on a marine energies based multi-source system, A. Roy, F. Auger, S. Bourguet, F. Dupriez-Robin, Quoc Tuan Tran, IREENA – Univesité de Nantes, CEA-Tech Pays de la Loire, INES CEA-LITEN/DTS/LSEI
5. Energy management system for a grid-connected wind farm and battery storage hybrid plant via MPC strategy, A. Aguilera-Gonzalez, R. Lopez-Rodriguez, I. Vechiu, ESTIA, Grenoble Institute of Technology
6. Energy management in a DC/DC resonant converters-based battery/supercapacitor hybrid system, M. Arazi, A. Payman, M. Camara, B. Dakyo, GREAH Université du Havre-Normandie

[1] Chaque présentation a une durée de 10 minutes pour l'exposé et 10 minutes pour les discussions

Impacts of SCs on battery lifetime in HESS on DC Microgrids in BiPV

Margot Gaetani-Liseo [1,2], Corinne Alonso [1,2], Bruno Jammes [1,2]

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Abstract: In this paper we present the first results of the work that we started few month ago in order to demonstrate the advantage of using Hybrid Energy Storage System (HESS) with batteries and Super Capacitors (SCs) in Low Voltage DC Micro-Grid (LVDC-MG) in residential application. To achieve this goal we study the impacts of the quantity of SCs on the battery lifetime, the HESS cost and the losses energy (energy that can't be store). This analysis has been done on the LVDC MG developed in LAAS-CNRS in ADREAM Building Integrated PhotoVoltaic (BiPV). The HESS is made by two types of Energy Storage System (ESS), SCs and OPzV lead acid batteries. The power profiles used for simulation are 1 year's data PV production and light consumption from one of the floor of the BiPV.

Keywords: LVDC MG, ESS, hybrid topology, Super Capacitor, lead acid battery, PV application, buildings

1. Introduction

To tackle the issue of reducing ecological footprint, we have to drastically change the way of how we are satisfying electrical demand in buildings (residential, commercial, industrial). Thus, buildings are responsible on much of 60% of global electrical consumption [1] and at the same time, they can be an electrical energy resource (ZEB, BiPV). But, the unforeseeable nature of the PV sources requires integrating ESSs to avoid the perturbation on the main grid. The aim of this work is to analyze the HESS interest with SCs on storage system lifetime and cost-efficiency, in buildings. This paper presents the first step of this study with the models and complete simulation tools developed on Matlab®. In the following section, we present the LVDC-MG topology, and then we explain the simulation process. Finally we discuss the preliminary results based on real PV production and light consumption power profiles recorded in ADREAM BiPV [2].

2. LVDC MG description

The LVDC-MG developed in LAAS-CNRS is descripted in [3]. Its global architecture is presented in Fig. 1. The HESS unity is made up of two elements connected in parallel on the DC bus.

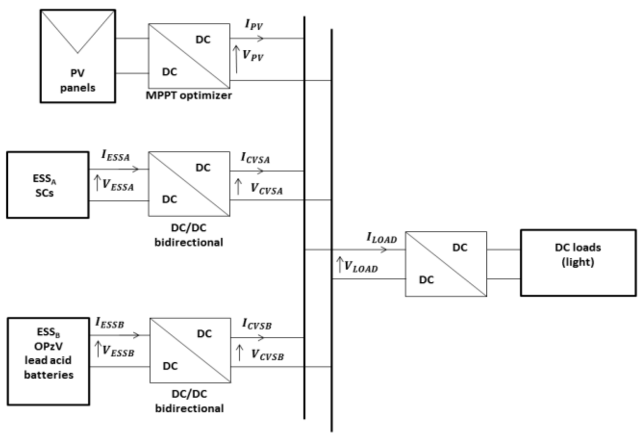

Fig 1 : Overall LVDC-MG topology

ESS A and B are respectively composed by SCs (165 F) and OPzV lead acid batteries (250Ah@C10) elements. They are associated in n_S series and n_P parallel elements to adapt the voltage and increase the total energy available. We choose to combine these two technologies because they have different characteristics and lead acid batteries are the most mature and cheaper electrochemical storage technology [4]. Association with SCs reputed for the high number of cycle that they can support, allow avoiding micro cycle in the batteries. In this way, we developed an energy management algorithm, derived from "DC bus signaling" control, which gives priority to SCs charge and discharge [3].

3. Simulation Algorithm

To achieve a better lifetime and limit constraints on the battery pack we restrict SoC range between 50% and 90%. Moreover, the C-rate is limited to 0.1C (25A) in charging and discharging mode. In a first approach, we used the common static model of batteries given by Eq. 1.

$$V_{ESSB}(t) = a_{ESSB} * SoC(t-1) + b_{ESSB} - R_{ESSB} * \Delta I_{ESSB}(t-1) + V_{ESSB}(t-1) \quad \text{Eq. 1}$$

We used two different parameters set for charging and discharging modes. They have been identified from experimental tests made thank to a battery cycler BioLogic BCS-815. We validated the voltage model with different current profiles, in our operating conditions, and obtain relative error lower than 6%. SCs are represented by a capacitor C_{SC} in series with a resistor R_{SC} (R_{SC} value is taken in the datasheet). The SC voltage equation is given by Eq. 2.

$$V_{ESSA}(t) = \frac{1}{C_{sc}} * I_{ESSA}(t-1) * \Delta t - R_{ESSA} * \Delta I_{ESSA}(t-1) + V_{ESSA}(t-1) \quad \text{Eq. 2}$$

Lastly, we added in simulation the converter efficiency model (η) of the DC/DC converters developed in LAAS-CNRS. The efficiency depends on ESS_i voltage and ESS_i

power (Eq. 3), where i is A or B ESS and f_k is a second order polynomial function.

$$\eta(P_{ESSi}(t),V_{ESSi}(t)) = f_1(V_{ESSi}(t)) * exp^{f_2(V_{ESSi}(t))*P_{ESSi}(t)} + f_3(V_{ESSi}(t)) * exp^{f_4(V_{ESSi}(t))*P_{ESSi}(t)} \quad \text{Eq. 3}$$

The parameters of the efficiency equation are identified from several automatized tests in buck and boost modes thanks to an automatize test bench. We simulate the operation of the HESS in Matlab® environment following the algorithm presented in the flow char diagram Fig 2. The inputs signal $P_{BALANCE}(t)$ is the difference between PV production $P_{PV}(t)$ and light building consumption $P_{LOAD}(t)$. In our work we used a 1 year dataset of power profiles with a sample period of 1min from our BiPV database.

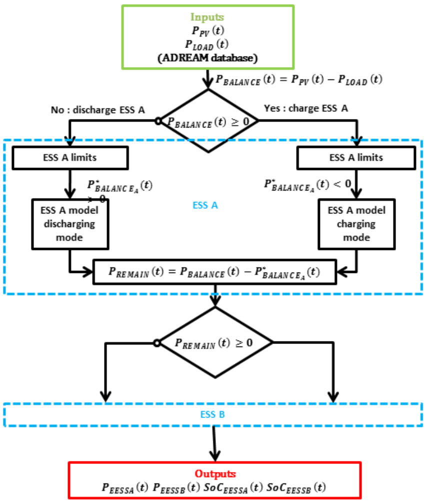

Fig. 2 : Flow chart diagram of HEES

4. Criterion

We analyzed the results according to the leveled cost LCOE HESS calculated as explain below. The time horizon choose for the study is 20 years, considering that correspond to the SCs lifetime [5]. The LCOE formula is given in Eq.4.

$$LCOE = \sum LCOE_i = \sum \frac{\sum_{t=0}^{T=20} \frac{Cost_i}{(1+r)^t}}{E_{dis\_i} * \frac{1-(1-r)^{-T}}{r}} \quad \text{Eq. 4}$$

With r is the discount rate equal to 7%, E_{dis_i} is the energy discharging during one year in €/kWh and $Cost_i$ is the global cost including investment cost and operating cost in euros. We choose worst case values coefficient from [5]-[6] in €/kWh and we calculate the $Cost_i$ depending on battery lifetime for each year of the simulation time horizon. L_A is fixed to 20 years and the battery's lifetime L_B is calculated using a rainflow counting method based on [7]. For estimated the lifetime in year we have to calculated CD, the cumulative damage made to the batteries at the end of the one year simulation (Eq. 5).

$$L_B = \frac{1}{CD} = \frac{1}{\sum \frac{n_{cycle}(DoD_k)}{N_{CF}(DoD_k)}} \quad \text{Eq. 5}$$

This method allows us to estimated L_B taking into account all the battery's cycle (n_{cycle}), with different DoD_k according to the number of cycle to failure (N_{CF}) given by the manufacturer. In order to analyze the interest of SCs in residential applications we compute simulation for different values of SCs in a given constant global quantity of storage energy available. Fig. 3 presents our first results.

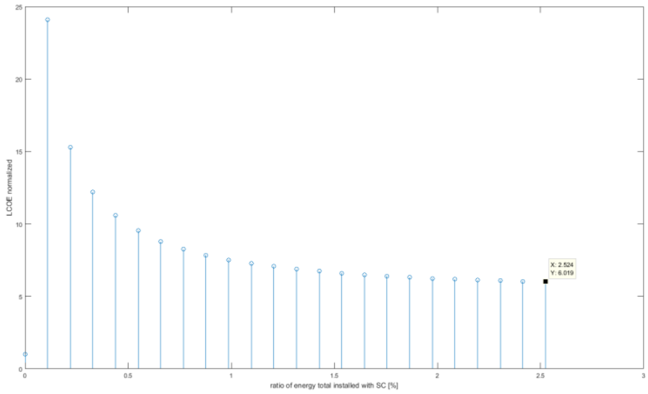

Fig 3: HESS LCOE for different values of SCs

We can see that the configuration with 2.5% of the total energy storage installed is made with SCs is six time more expansive that configuration with OPzV lead acid batteries only, and the LCOE seems converged to this values.

5. Conclusion and Future works

To conclude, our first results about impact of SCs in an HESS in LVDC-MG show that SCs allows improving battery lifetime but not enough to accelerating the depreciation. However to achieve this study it would be interesting to add additional cost included in the HESS Life Cycle Analysis. We have also to do the same analysis with different ESSs technology and load profiles (DC loads as computers…). Furthermore, we can complete this work by adding studies about impacts of ageing estimation methods or using others criteria like GHG emissions for example.

6. References

[1] IEA, “Electricity information: Overview version 2017.”

[2] LAAS-CNRS, “ADREAM project.” [Online]. Available: https://www.laas.fr/public/fr/le-projet-adream. [Accessed: 10-Jan-2017].

[3] J. Dulout, C. Alonso, L. Séguier, and B. Jammes, “Development of a photovoltaic low voltage DC microgrid for buildings with energy storage systems,” in *ELECTRIMACS 2017*, 2017, vol. 2017, p. 6p.

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[7] R. Kanapady, K. Y. Kyle, and J. Lee, “Battery life estimation model and analysis for electronic buses with auxiliary energy storage systems,” in *Applied Power Electronics Conference and Exposition (APEC), 2017 IEEE*, 2017, pp. 945–950.

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JSN - 2018

9 juillet 2018, Compiègne, France

BATTERY VOLTAGE INCREASE BASED ON DC/DC CONVERTERS IN PARALLEL ASSOCIATION

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Abstract – Parallel architecture integrating low voltage batteries allows an individual control of their discharge. But the coupling of step-up converters supplied by batteries is more difficult to realize than that of solar optimizers, because of the ability of each battery to supply alone all the current needed by the load. In this paper we show how it is possible to distribute almost the same current in each battery, allowing regular discharge, without sophisticated medium of communication.

Keywords – DC micro-grid, Photovoltaic modules, Pb-acid batteries, Step-up converters, Parallel architecture.

1. INTRODUCTION

DC power bus in PV stand-alone systems are typically based on serial association of Pb-acid batteries, using often 12V or 24 V DC units for reasons of cost. But the main disadvantage of this architecture is a great sensitivity of cells mismatches inducing unequal ageing. Parallel architectures have been soon proposed, based on converters with dual function (battery charge and voltage raising) [1] [2], but without description of phenomena induced by output coupling. In this paper we propose to study the behaviour of DC/DC step up converters in such configuration, and connected to low voltage batteries with different open circuit voltages.

2. PARALLEL ARCHITECTURE

2.1. COUPLING OF DIFFERENT STORAGE UNITS

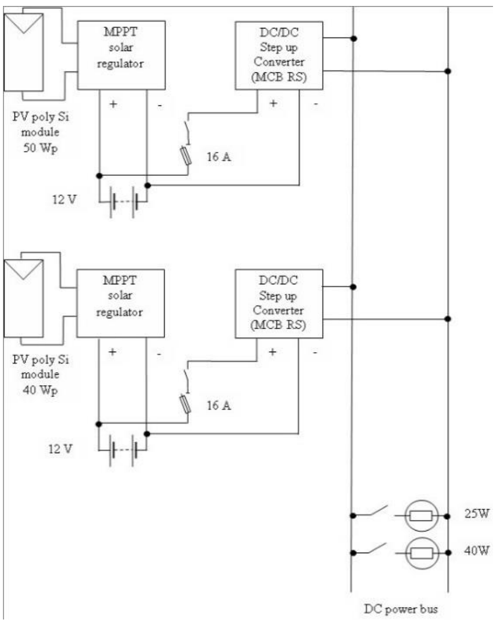

Fig. 1. Parallel architecture

In figure 1, every storage unit is charged at the Maximum Power Point (MPP) of a PV module and different roof exposures are simulated by different module peak powers. Battery voltages are boosted by DC-DC converters developed in laboratory [3]. To prevent failures, software current limitations are implemented in addition to overcurrent protection (fuse).

2.2. DATA ACQUISITION SYSTEM

Six electrical variables are acquired by a commercial USB module, displayed and saved by a virtual instrumentation software (Labjack/Profilab): current and voltage of each battery and of course current and voltage of power bus. The measurements are processed by Matlab software.

3. STRATEGIES OF PARALLEL INJECTION

3.1. CONTROL WITH FIXED DUTY CYCLE (OPEN LOOP)

The same control software is implemented in each converter.

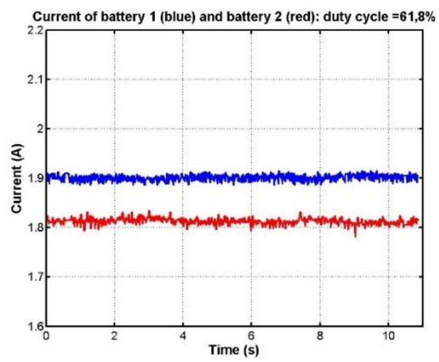

Fig. 2. Battery currents in open loop

Knowing voltage of each battery and setting output voltage, it is easy to calculate duty cycle with following formula [4]:

$$\alpha = \frac{\frac{V2}{V1} - 1}{\frac{V2}{V1} + m} \quad (1)$$

with V1 as the battery voltage, V2 as the power bus voltage and m as the transformer ratio, equal to 6.

Duty cycle is calculated for battery 1, with voltage equal to 12.4V, fixing output voltage to 155 V.

In Fig. 2 are shown the two battery currents, which are not quite the same. As voltage of battery 2 is lower than voltage of battery 1, the duty cycle value should be higher with output voltage imposed by converter 1, so current injection is lower.

3.2. OUTPUT VOLTAGE REGULATİON

With the objective to discharge fairly each battery we choose to experiment a regulation of power bus voltage on the base of a precedent study [5]. Absolute voltage reference is excluded for each converter because there is a mismatch between the voltage divider bridges used in converters. So, it is decided to set an absolute reference for only one converter and a measured reference obtained from actual output voltage for the other.

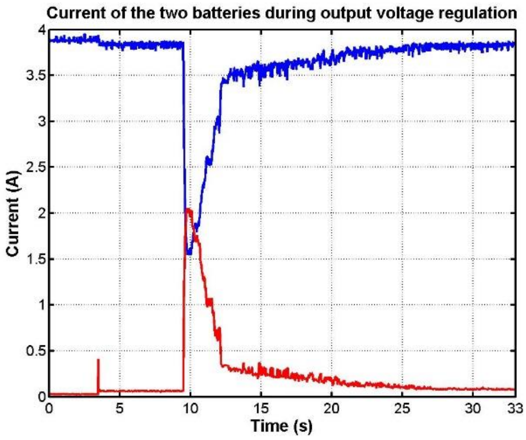

Fig. 3. Current of battery 1 (blue) and battery 2 (red)

In Fig. 3, the converter of battery 1 regulates output voltage during all the experiment with a fixed reference and an integral action. Battery 2 is connected at 3.5 seconds and a fixed duty cycle is applied (48.9%). A little current equal to 60 mA appears. At 9.5s the converter of battery 2 begins to regulate the output voltage with the measured reference. Quickly, current of battery 2 exceeds current of battery 1, but the phenomenon is not steady and finally the converter of battery 1 regulates alone the output voltage again.

As an explanation we suppose that initial fixed duty cycle of battery 2 is too low, implying rough transient phenomenon. A higher value like 60% should allow current stabilization: hypothesis to verify in future study.

But even if the initial duty cycle is inappropriate, the behaviour of converters may differ in some experiments, not exhibited in this paper. The two batteries are able to supply together power to the loads. But currents are not the same: for example, on average, 1.16 A for battery 1 and 2.55 A for battery 2 in another experiment. But the system is not steady in the long term, which leads us to experiment another strategy mixing output voltage regulation and battery current regulation.

3.3. VOLTAGE AND CURRENT REGULATİONS

The idea is to set a current reference for the battery 2 in the middle of necessary current to supply power bus if alone. To prevent battery 1 to inject, the second converter is allowed to regulate temporarily output voltage with higher reference.

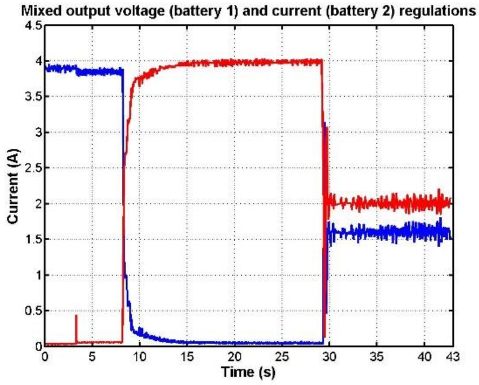

Fig. 4. Current of battery 1 (blue) and battery 2 (red)

At 8.2 seconds a little higher (0.5 V) voltage reference is applied to the second converter before the current regulation, whose effect is seen at 29.3 seconds. Stabilization is obtained in less half second, even if significant and steady ondulation is seen on the two currents (disadvantages of integral action). But overcurrent does not exceed 13% and 10% respectively for battery 1 and battery 2, relative to average values. In this case the current of battery 2 (2.01 A) is 25% higher than that of battery 1 (1.60 A).

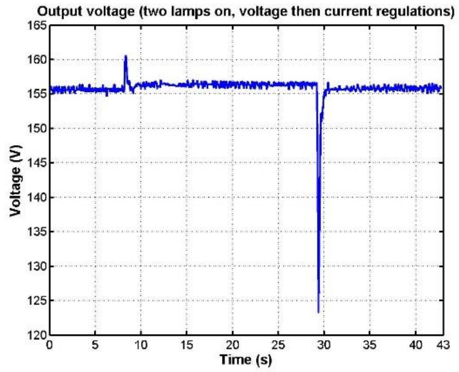

Fig. 5. Output voltage regulation by converter 1

Effects on output voltage are highlighted Fig. 5: first, when the reference of output voltage is modified, a transient peak of 3 % appears at 8.2 seconds followed of real 0.7 V increase, and secondly, when an important drop of voltage occurs at 29.3 seconds, due to the beginning of current regulation. Converter 1 controls output voltage again with initial reference, supplying necessary current.

4. CONCLUSİON

In the first strategy, with fixed duty cycle, the battery with the highest voltage imposes output voltage, preventing the weakest battery to supply the same current. In the second strategy, stability is not guaranteed and the current of one battery may be equal to zero. In the third strategy, current regulation ensures stability of power supply, but taking into account impedance variations of load will lead us to design a complete exchange protocol between converters, based on the variations of the output voltage level for example.

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Systèmes d'Énergie Électrique dans leurs Dimensions Sociétales - GdR 2994

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VARIABLE SPEED DIESEL-PV POWER GENERATION FOR MICRO-GRID APPLICATIONS

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Abstract - **This paper deals a multi-source system dedicated to isolated areas. The hybrid electric system includes: 2.5 kW variable speed diesel generator, 3.7kW photovoltaic generator, and a pack of lithium-ion battery. The system is connected to an electrical micro grid through a power-controlled 3-level NPC inverter. The variable speed diesel generator is used as the main energy source which ensures the DC-bus voltage control through a 3-level NPC rectifier controlled by the vector Pulse Width Modulation (PWM) strategy. The photovoltaic generator is used to increase the renewable energies penetration ratio for the system. Finally, the battery pack is proposed to compensate the intermittent energy from PV. Simulations are done using Matlab software to illustrate the scenario.**

Keywords- Active and reactive power control; three-level converters; Permanent Magnet Synchronous Generator (PMSG); Variable speed control; Maximum Power Point Tracking (MPPT).

I. INTRODUCTION

The depletion of fossil fuels has in part sparked a real fascination for renewable energies in the world. The intermittence of these energies remains their main weak point. In order to increase the energetic autonomy and optimize the production of electrical energy, multisource systems can be put in place by combining these sources of renewable energy with other sources such as the diesel generator and storage units. In this paper, the authors propose a multi-source system based on: 2.5 kW variable speed diesel-generator used as a main source for DC-bus voltage keeping via a three-level NPC rectifier; 3.7kW PV-generator that supplies intermittent current in DC-bus; and a 86Ah/ 158V pack of batteries. The DC-bus voltage is converted into an alternating one in order to transfer it to the micro grid with phase-to-phase RMS voltage of 400V, through a power-controlled NPC three-level inverter. Multi-level converters are chosen due to the advantages they offer for high and low power systems, in particular the elimination of sudden changes in voltage, which cause common-mode voltages across machine, especially when the rectifier switches with high frequency.

But also the elimination of harmonics prohibitive for the system, which increase the losses in the load and the converters. The configuration of the system is illustrated in Fig.1.

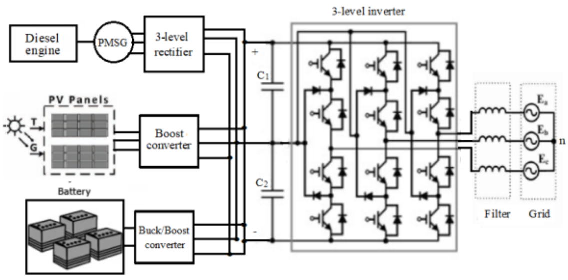

Fig. 1: Multi-source system configuration.

II. MULTI-SOURCE SYSTEM CONTROL

A. DC-bus control strategy

The three-level rectifier connected to variable speed diesel generator [1] is used to control the DC-bus voltage. The used approach is based on the vector control method which presents a faster internal loop and a slower external one as illustrated in Fig.2. The *d-axis* loop is used to control the DC-bus voltage when the reference is set to a constant value and the *q*-axis loop is used to impose a zero reference current I_q^*. The frequency approach energy management strategy is used for power sharing between the sources according to their dynamics.

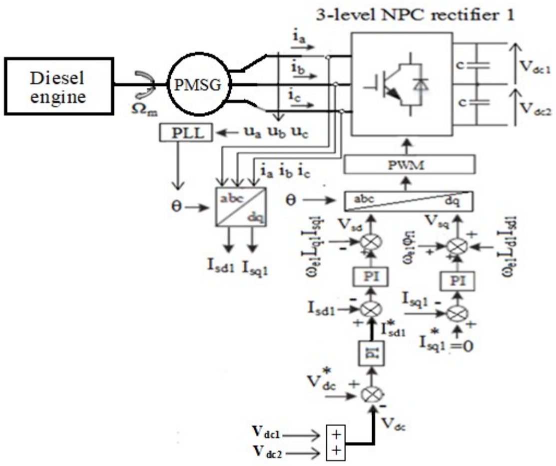

Fig.2: DC- bus voltage control.

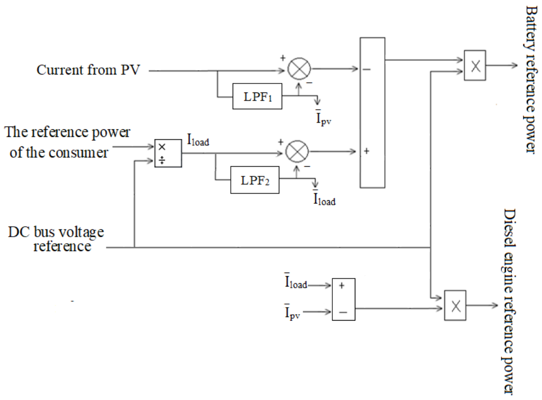

Fig.3: Frequency approach.

The used method for the high and low frequency components extraction is illustrated in Fig.3. More information about this method can be found in [2].

B. *PV-Generator power control strategy*

The PV-generator is associated with a three level boost converter illustrated in Fig.4. The control strategy is based on MPPT using the perturb and observe technique. The PI controller is used to minimize the MPPT error "e" which leads to estimation of the duty cycle D1. This control loop is ncessary to balance the voltages (V_{dc1} and V_{dc2}) of the two capacitors in DC-bus. In other terms, to ensure the voltages balance of the two capacitors this control loop is essential. This last one is used to generate ΔD component which is used to caculate the second duty cycle D2 as follows: D2=D1+ΔD, [3][4] .

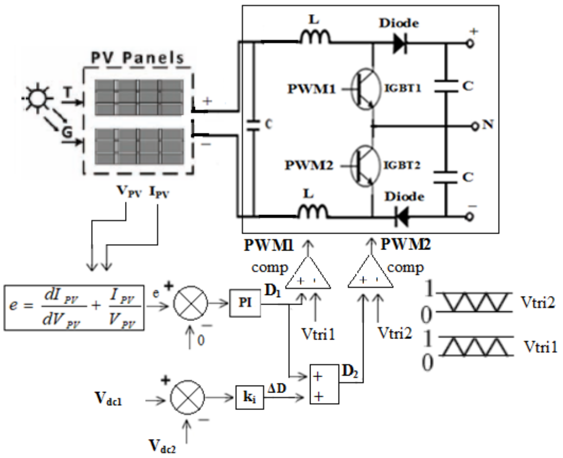

Fig.4: PV –generator and DC-DC boost converter control strategy.

III. DIESEL-PV SYSTEM SIMULATION RESULTS

A. *Simulation conditions*

The active and reactive power control method is described in [1]. The system simulation is performed in following conditions: - the active power reference P* is fixed according to the electrical grid-code requirement; -the reference of the reactive power Q* can be computed using equation (1).

$$\begin{cases} \tan(\Psi) = \pm 0.327 \\ Q^* = P^* \cdot \tan(\Psi) \end{cases} \quad (1)$$

DC-bus voltage reference $V_{dc\text{-}ref}$ is fixed to 430V. By convention, the sign of the power (active and reactive) is assumed positive for the supplied power and negative for consumed power. The PV system is based on three parallel strings and fours modules in series with 96 cells in series for each module. The maximum power of the one module is 305W. The irradiance is variable and similar to the PV power curve.

B. *Simulation results*

The multi-source system simulation is done in Matlab software environment. Fig.5 shows the control result of the DC-bus voltage, where the measured voltage is much closed to its reference except during the initial state which presents an overrun between the reference and the simulations result. The voltages of the DC-bus capacitors are balanced as illustrated in Fig.5. Fig.6 shows the active power control. This control is satisfactory because the measure power follows the reference one. The reactive power control result is shown in Fig.7. It can be noted that the system reacts perfectly to the following scenarios:

- Operation for $Q^*>0$ corresponds to time between 0 and 25 s, where the system supplies the reactive power to the power grid.
- Operation with unit power factor $Q^*=0$ corresponds to time from 20 to 32s.

- Operation for $Q^{*}<0$ corresponds to time between 32 and 50 s, where the system absorbs the reactive power from micro-grid.

Fig.8 illustrates the battery power control. This control result shows a good correlation between the measured power and its reference.

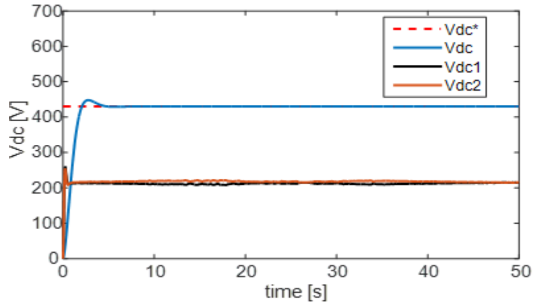

Fig.5: DC-bus voltage and Capacitors voltages balancing control result.

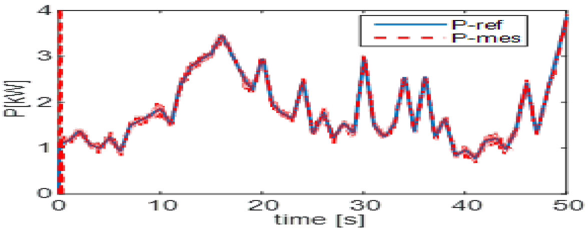

Fig.6: Active power control result.

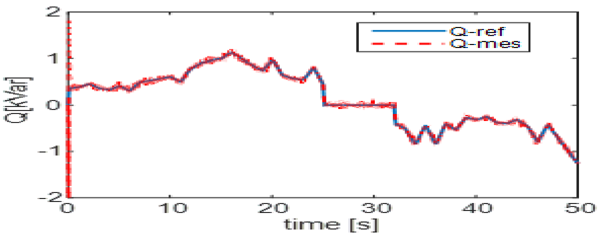

Fig.7: Reactive power control.

Indeed, the positive power corresponds to the batteries discharge process and the negative power presents the energy storage phases by the pack of the batteries. Fig.9 shows the contribution of the variable speed diesel generator. This contribution is close to estimated power profile in Fig.3. The PV power is presented in Fig.10 which varies according to daily irradiance and the fluctuations due to Shading effects.

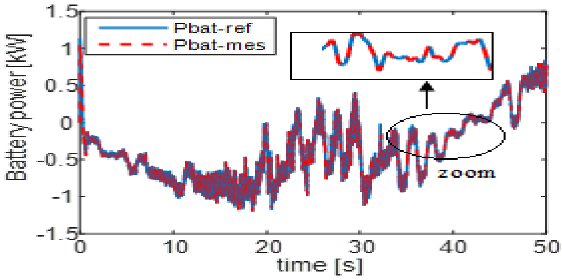

Fig.8: Battery power control.

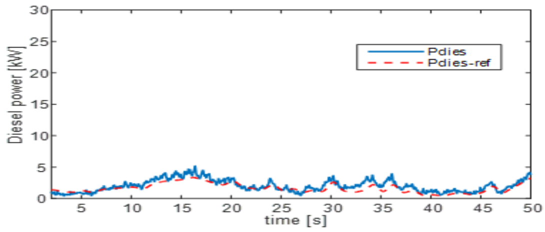

Fig.9: Diesel power control.

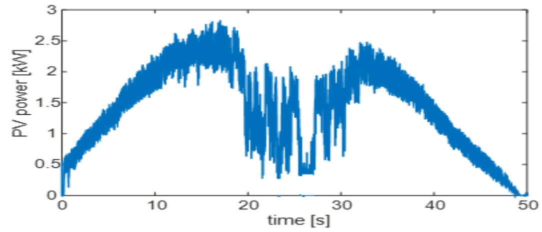

Fig.10: PV contribution.

IV. CONCLUSION

In this paper, the authors have presented the control strategies of the multi-source system based on Permanent Magnet Synchronous Generator for variable speed diesel connected to electrical grid and the PV-batteries module. Proposed control strategies are focused on PMSG speed control, DC-bus voltage control, the active and reactive power control, and PV power management. The simulations results show that, the proposed control strategies are satisfactory and the controlled variables are very close to the references ones. Moreover the batteries integration is done in order to compensate the fluctuations of the power produced and the voltages balancing for the midpoint DC-bus capacitors to avoid their destruction.

ACKNOWLEDGEMENT

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IMPACTS OF DEMAND SIDE MANAGEMENT STRATEGIES APPLICATION ON A MARINE ENERGIES BASED MULTI-SOURCE SYSTEM

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Abstract – So as to foster marine energies integration for islands electricity supply, anticipation based demand side management strategies are applied to a multi-source system based on solar, wind, tidal and wave energies. To ensure the demand is satisfied in case of low generation, lithium-ion batteries are used. The developed strategies concern the electric heating and water heater power demand of the Ouessant Island. Positive effects on demand satisfaction, battery lifetime, system sizing and costs are observed in the carried out simulations, showing the positive effects brought by the anticipation based strategies in case of excess generated power.

Keywords – Offgrid system, Demand Side Management strategies, marine energies, island electricity supply

1. INTRODUCTION

In marine remote areas, electricity supply is mostly provided by solar and wind energies. Batteries and genset are often used to ensure the demand be met in case of low generation. In addition to the pollution generated by the use of gensets, fuel import is sometimes costly due to logistical constraints in some remote areas. Avoiding the use of gensets leads to more constraints on reliability, sizing and costs of a system based on renewable energies and battery. So as to foster the integration of renewable energies available around an island, such as solar, wind, tidal and wave energies, and to bring flexibility to the energy management strategies [1], Demand Side Management (DSM) strategies are developed in this work. Water heater and electric heating loads are often considered in papers dealing with DSM [2,3]. In this work, anticipation strategies are simulated for both of these loads, instead of delay shifting strategies usually applied. The case study concerns the Ouessant Island. Section 2.1 describes the considered multi-source system. The developed DSM strategies are presented in Section 2.2, resulting in several benefits summarized in Section 3.

2. METHOD

2.1. MUTLI-SOURCE SYSTEM DESCRIPTION

The offgrid multi-source system considered is made of four sources, according to the overview given in Fig. 1. At each time sample t_k, the total generated power P_{gen} corresponds to the sum of powers generated by photovoltaics panels (P_{PV}), wind turbines (P_{WT}), tidal turbines (P_{TT}) and wave energy converters (P_{WEC}). In order to ensure the demand power P_{dem} be met in case of low production, a lithium-ion battery is added to the multi-source system. Battery model evaluates at each time sample the State of Charge (*SoC*) and the State of Health (*SoH*). The Ouessant Island case study is considered (located on the west coast of France) as the tidal kinetic and the wave resources reach a sufficiently level to consider their exploitation. The availability of both resource and load profile data allows to conduct simulations for a five years period at hourly time step, from 01/01/2011 to 31/12/2015.

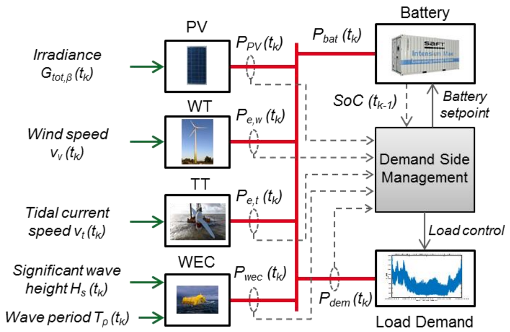

Fig. 1. Overview of the considered multi-source system model

The load profile data are based on EDF SEI data [2], corresponding to the Ouessant island hourly load demand. Electricity demand is mostly attributed to the domestic needs. The annual energy consumed by the residential sector amounts to 70% of the total energy. The other part is related to the tertiary sector (the economic activity of the island is mostly related to tourism). According to this profile and to the information available in [3], a load profile separation is carried out according to the following hypothesis, resulting in three load profiles:

- *Electric heating*: a thermo-sensibility analysis is conducted. A linear regression is done on the load demand vs. average air temperature measurements. The power P_{HT} related to electric heating is considered as a constant during the whole day.

- *Water heater*: profile extraction is based on the electricity tariff policy applied in France, considering that water heaters operate at a constant power P_{WH} for eight hours during the night (between 21h p.m. and 5h a.m.), i.e. during the low price policy period.
- *Non-shiftable loads*: the rest of load profile is considered as the non-shiftable power consumption P_{ND}.

Thus, at each time sample, the total demand power can be defined as:

$$P_{dem}(t_k) = P_{HT}(t_k) + P_{WH}(t_k) + P_{ND}(t_k) \quad (1)$$

2.2. Developed Demand Sİde Management Strategİes

Among all the existing DSM strategies, time shift based strategies are applied in the system simulation flowchart (Fig. 2.) if the battery is fully charged (State Of Charge evaluation) and according to the following rules:

Water heater strategy: For water heating management, a shifting strategy based on load anticipation is considered. If at a time sample t_k the generated power is larger than the demand, water heaters are turned on before their initially planned working time, whatever the power amount generated later. Anticipation window time starts ten hours before the initial period and finishes at the end of initial period. The anticipated consumption is limited by the excess power at t_k and cannot overpass the initially planned water heater power.

Electric heating strategy: Anticipation is also considered for electric heating, but with a shorter window time and only in case of subsequent deficiency. In case of excess production at t_k, the electric heating load planned at a future time sample t_{k+A} is anticipated, only if generated power at t_{k+A} is lower than the demand. Anticipation time window is limited to three hours ($1 < A < 3$) and constrained by the available power at t_k and the lack of power at t_{k+A}, to limit the discomfort brought by this DSM strategy. A perfect forecasting ability is considered in this strategy, as the generated power is evaluated according to the resource data time series.

3. Results

A simulation is carried out over a five years long period at hourly time step. The most significant observed benefits are:

- Battery lifetime: by using the excess of generated power to supply shiftable loads, the battery use is avoided thus the state of health degradation is slowed down.
- Unmet demand: according to the Loss of Power Supply Probability (LPSP) and unmet load hours, unmet load rate is reduced.
- Number of batteries required for the demand to be fully satisfied: according to the sources configuration and the considered year, a reduction can be observed.
- Cost: by reducing the required number of batteries, LCOE (Levelized Cost of Energy) can be reduced.

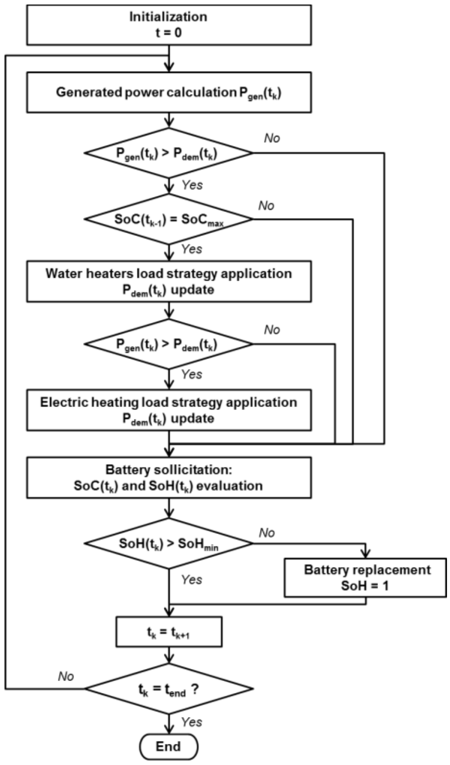

Fig. 2. Simulation flowchart including DSM strategies

4. Conclusİon

The anticipation based strategies applied on water heater and electric heating loads allow the load satisfaction to be improved and the battery lifetime to be extented. Unlike the strategies which consider the load delay, the anticipation based strategies present less discomfort for the user and reduce loss of power supply situations since excess power is used for shiftable loads supply.

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Systèmes d'Énergie Électrique dans leurs Dimensions Sociétales - GdR 2994

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ENERGY MANAGEMENT SYSTEM FOR A GRID-CONNECTED WIND FARM AND BATTERY STORAGE HYBRID PLANT VIA MPC STRATEGY

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Abstract - In this paper, an energy management system (EMS) based on model predictive control (MPC) and quadratic programming (QP) is presented. The control strategy manages the power performance of an island grid-connected hybrid plant combining a wind energy conversion system (WECS) and a Li-ION battery energy storage system (BESS). The energy management system is tested by using real wind data.

Keywords – Energy management system, Li-ION battery, wind turbine, model predictive control, renewable energies.

1. INTRODUCTION

In recent years, developments in wind energy generation have allowed an increased employment of this renewable energy source. However, this also increases the problems that arise when the quantity of wind energy increases into the electricity networks. The main problem that must be faced is the intermittent nature of wind power and the occasional large fluctuations due to random behaviour of weather conditions. This phenomenon needs to be handled in order to prevent undesirable effects on the stability of electrical grids [1].

A feasible technical solution is by integration of battery storage systems (BSSs) with wind farms. When paired with wind turbines, battery storage systems add the capacity to absorb power production fluctuations and to adjust the power output. In this manner, it is possible to avoid these undesirable effects and providing at the same time, added value through greater reliability, improved power quality, and energy availability.

In a grid-connected wind farm and battery storage hybrid plant, the dispatch of generation and storage resources to meet day-ahead power production plans requires an energy management system (EMS). Commonly, these EMSs are focused not in one but in several objectives at the same time (making the maximum possible profit, obtaining the minimum possible losses, etc).

In this paper, an EMS based on Model Predictive Control (MPC) is proposed to hand the battery's charge/discharge cycles and state-of-charge (SoC) efficiently, in the interest to maintain the generation engagements while considering the BESS lifespan.

The proposed MPC is based on the Shepherd equations model representing a Li-ION battery system, which is used to predict the future output behavior of the BESS. The EMS is tested by using real wind data.

2. HYBRID POWER PLANT

The EMS has as main objective, to dispatch power from the wind farm and battery storage hybrid plant to the electricity grid according to the variations of electricity price and peak/off- peak periods in a day. For this, a reference power signal is generated varying dynamically with the status of electricity price and power hybrid plant production, which can be tracked by the control system. The basic structure of the system in a grid-connected mode is illustrated in Fig. 1.

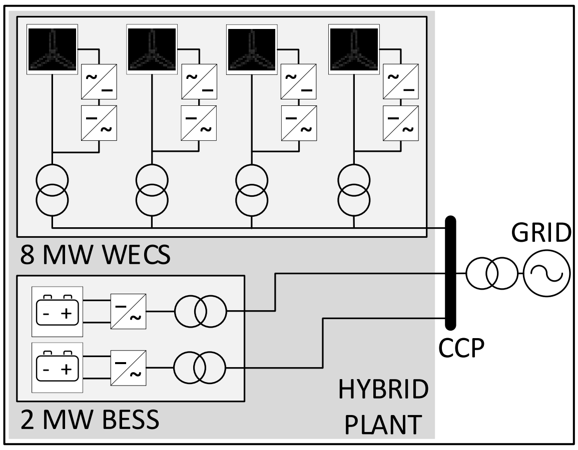

Fig. 1. Wind farm and battery storage hybrid plant.

The plant must supply power continuously and in accordance with an injection band. The band disrespect leads to penalties reducing the power plant profits. The proposed strategy aims at maximizing the profit through the minimization of the occurrence of penalty conditions [2].

3. BATTERY MODEL VALIDATION

The battery-systems play an important role in the smart grids. These tasks include, among others, specific aspects such as the load leveling, the power system stabilization and the response in emergency cases. For these reasons, the EMS proposed here considers a battery system whose model is used to predict the future output behavior of the BESS, in order to manage in an optimized way the power plant injection into the grid.

Combining the Shepherd's model, which describes the electro-chemical behaviour of the battery based on the chemical processes, and a state-space representation considering only the battery nominal zone, a dynamic discrete model is given via an equations system representing the charge and discharge cycles.

Shepherd's model gives a most accurate battery model in terms of terminal voltage, open circuit voltage, and internal resistance, discharge current and state-of-charge [3]. From this, a voltage-current equivalent circuit model which describes how the terminal voltage of the battery changes with the current, is presented as follows:

$$\begin{aligned} V_{ch} &= E_0 - R\, i_{batt} - K_{cr}\, i^* \frac{Q}{i_t - 0.1Q} - K_{cv}\, i_t \frac{Q}{Q - i_t} \\ V_{dch} &= E_0 - R\, i_{batt} - K_{dr}\, i^* \frac{Q}{Q - i_t} - K_{dv}\, i_t \frac{Q}{Q - i_t} \end{aligned} \qquad (1)$$

In this paper, considering only the battery nominal zone, the dynamic discrete state-space representation is proposed considering a vector of three states, being x_1 the capacitor current, x_2 the battery current and x_3 the state-of-charge of the battery, and the input u is the battery current i_{batt}:

$$\begin{aligned} x_1(k+1) &= x_1(k) + u(k+1)\,\Delta \\ x_2(k+1) &= \alpha\, u(k+1) + (1-\alpha)\, x_2(k) \\ x_3(k+1) &= 1 - \frac{x_1(k+1)}{Q} \end{aligned} \qquad (2)$$

The model representation proposed here, it is validated comparing with the SimPowerSystems battery model proposed by [3], which is available on ®Simulink platform.

4. MPC CONTROL STRATEGY

The MPC controller is designed by using a battery state-space model, which based on the current information of the state variables at the current time to predict the future states. In order to maintain a supply power continuously (P_{inj}=P_{wind}+P_{batt}), and in accordance with a predefined injection band, two main rules for the hybrid plant operation are established: first, a power fed (P_{eng}) into the main grid minimizing the exceeding according to the injection limits. And second, the respect of the limits for the battery state-of-charge [2].

Concerning to the respect of the injection band, a tolerance region is established using upper and lower limits on the ceiling and on the floor of the injection band, where the tolerance *tol* is defined as the 25% of the installed plant generation capacity.

$$P_{eng} - tol \le P_{inj} \le P_{eng} + tol \qquad (3)$$

Here, the use of these references implies that the controller should research optimal solutions inside of this reference zone, but the injection power is not forbidden to go beyond the tolerance region. In extreme cases, it is possible that the injection power should be forced to go outside of these limits, which can entail penalties.

Also, the EMS strategy was also designed to focus on the maximization of the battery SoC. For this, constraints are used to restrain the possible solutions into the interval [20%, 80%], in order to extend the battery system lifespan, according to the datasheet of a commercial battery. This choice allows having more charge stored, which means that more battery power is available to cope with the deficits of power during low wind periods. Hereafter is presented the formulation of an energy management system based on MPC and QP proposed to achieve the plant operation according to the rules defined.

These constraints made that the MPC algorithm aware of the BESS limits, whereas the formulation of the objective function allows to satisfy the reference power objective, respecting the injection band. The MPC strategy calculates the set of future control actions optimizing a cost criterion to keep the system as close as possible to the predefined reference trajectory [4].

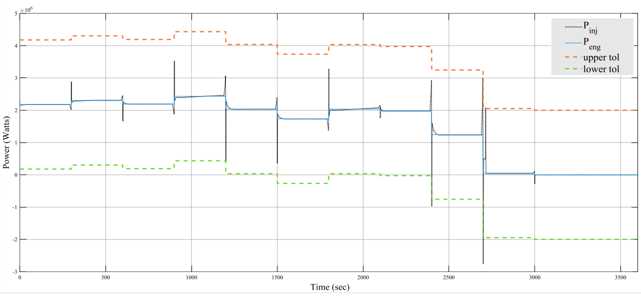

Fig. 2. Injected power by the hybrid plant using MPC.

The EMS is tested via ®DIGSilent/®Matlab using real wind data. In Fig. 2 it can be seen that the proposed algorithm keeps the power fed into the grid inside the tolerance region.

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Systèmes d'Énergie Électrique dans leurs Dimensions Sociétales - GdR 2994

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ENERGY MANAGEMENT IN A DC/DC RESONANT CONVERTERS-BASED BATTERY/SUPERCAPACITOR HYBRID SYSTEM

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Abstract - This paper presents a control strategy of an electrical hybrid system composed of a battery bank as the main energy source and a bank of supercapacitors (SC) as the auxiliary power source. The proposed approach relies on the energetic behavior of the sources to share the required power. To guarantee high power density and high efficiency, the battery bank is connected to a DC-bus via LLC resonant converter, while the SC bank is coupled to the DC-bus through a symmetrical bidirectional CLLC resonant converter. The simulation results prove the efficiency of the proposed energy management strategy as well as the performance of the resonant converters.

Keywords – Resonant Converters, Battery, Supercapacitor, Hybrid System and Energy Management.

1. INTRODUCTION

Association of the batteries as high energy density source and supercapacitors as high power density source can extend the batteries lifespan by reducing their dynamic stress and the peak power. However, the problem of using more than one source is the energy management [1], [2]. This paper deals with this problem and proposes an energy management strategy that relies on dynamics behavior of the energy source to share the required power with the load.

The main key in the electrical hybrid system based on DC-bus configuration is the DC-DC converters that connect the different sources to the DC-bus. Different topologies for energy and power sources association are presented in the literature. Non isolated bidirectional Buck-boost converters topology was proposed to interface battery and supercapacitors [3], [4]. In fact, many susceptible loads requires galvanic isolation specially if the voltage ratios between two sources is high. Some isolated topologies developed from the Dual-active Bridge (DAB) converter are proposed for electrical hybrid systems, as the triple active bridge converter [5], and four-port converter [6]. However, these topologies become infected with the complexity of the power flow direction regulation and control and they suffer from the limited soft switching range of the DAB converter. This paper proposes the utilization of isolated resonant converters that allows soft switching for the whole load range. Batteries are connected to the DC-bus via unidirectional LLC resonant converter [7], while the supercapacitor bank is coupled through CLLC bidirectional resonant converter [8]. Fig.1 shows the studied system.

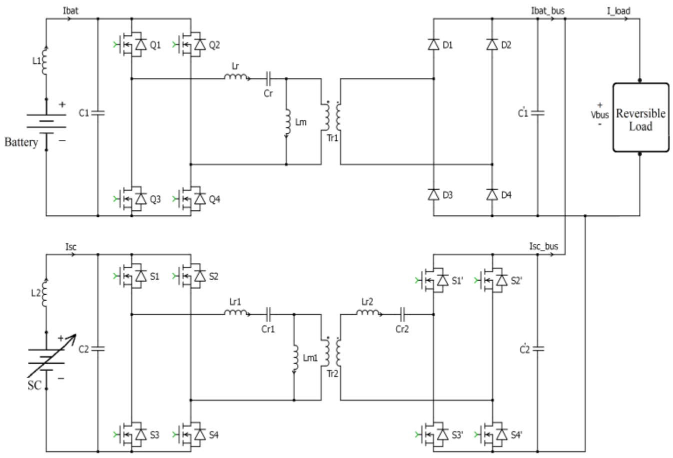

Fig. 1. Structure of the hybrid system.

2. DC/DC CONVERTER TOPOLOIES

2.1. LLC RESONANT CONVERTER

In this hybrid system, isolated LLC resonant converter is used to connect the batteries bank to the DC-bus. Its topology is illustrated in fig.2. Frequency modulation is used to control the converter which allows ZVS for primary bridge switches and Zero Current Switching (ZCS) for secondary rectifier diodes.

Standardized form of voltage gain is described in (1), where Q is the quality factor, γ is the inductors ratio and fr is the resonant frequency. The voltage gain versus the normalized frequency for several load conditions is presented in Fig.3 In our application, the converter is used as a boost converter and thus, the operation zone is located at zone 2 in Fig.3 to guarantee ZVS operation for primary switches and ZCS for rectifier diodes. Parameters of the converter are given in Table 1.

$$H = \frac{mV_o}{V_i} = \frac{1}{\left[1+\gamma-\frac{1}{f_n{}^2}-\frac{\gamma}{f_n{}^2}\right)\Big] + j\left[Q.\left(\frac{\gamma.f_n}{\gamma+1}-\frac{1}{f_n}\right)\right]} \quad (1)$$

$$\gamma = \frac{L_r}{L_p} = \frac{1}{k} \quad (2)$$

$$Q = \frac{1}{R}\sqrt{\frac{L_r}{C_r}} \quad (3)$$

$$f_n = \frac{f_s}{f_r} \;;\; f_{r2} = \frac{1}{2\pi\sqrt{L_e C_r}} \;;\; f_{r1} = \frac{1}{2\pi\sqrt{L_r C_r}} \quad (4)$$

$$R_e = \frac{V_o}{I_o} = \frac{8}{\pi^2}R \quad (5)$$

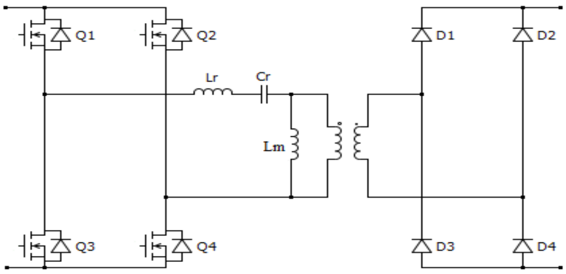

Fig. 2. LLC resonant converter topology

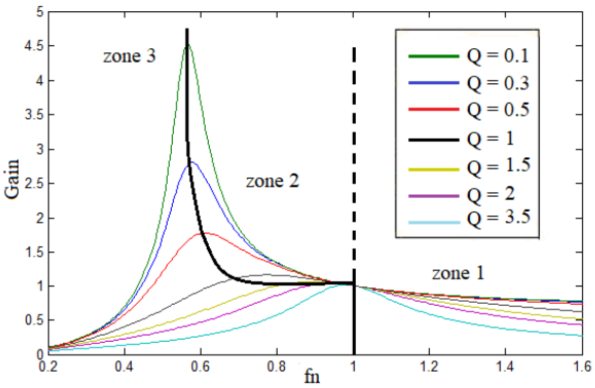

Fig. 3. Voltage gain of LLC resonant converter

Table 1. LLC resonant converter parameters

NAMES	PARAMETERS	VALUES
Batteries bank voltage range	V_{bat}	*60-100 V*
DC-bus voltage	V_{bus}	*270 V*
Transformer turn ratio	η_{LLC}	4
Magnetizing inductance	L_m	*15µH*
Series resonant inductance	L_r	*4 µH*
Series resonant capacitor	C_r	*0.9 µF*
Series resonant frequency	F_{r1}	*83kHz*

2.2. CLLC BIDIRECTIONAL RESONANT CONVERTER

The SC bank is connected to the DC-bus through a bidirectional CLLC resonant converter to ensure energy sharing with the load and the batteries bank. The topology of converter is illustrated in Fig.4 and the voltage gain is given by (6). The CLLC converter parameters are given in Table 2.

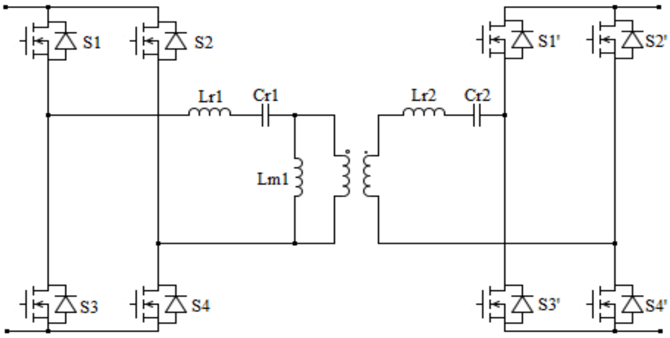

Fig. 4. CLLC resonant converter toplogy

$$H = \frac{f_n{}^3}{(f_n{}^3.\ a)+j(Q^2.b^2)} \quad (6)$$

With:

$$a = f_n{}^2(1+\gamma)+\gamma \;;b = f_n{}^4 - f_n{}^2(2+\gamma)+\gamma \quad (7)$$

Table 2. CLLC resonant converter parameters

NAMES	PARAMETERS	VALUES
Supercapacitors bank voltage range	V_{sc}	*50-100 V*
DC-bus voltage	V_{bus}	*270 V*
Transformer turn ratio	η_{CLLC}	4
Magnetizing inductance	L_{m1}	*15µH*
Primary series resonant inductance	L_{r1}	*4 µH*
Primary series resonant capacitor	C_{r1}	*0.9 µF*
Series resonant frequency	F_{r1}	*83kHz*
Secondary series resonant inductance	L_{r2}	*65 µH*
Secondary series resonant capacitor	C_{r2}	*0.09 µF*
Secondary resonant frequency	F_{r2}	*65kHz*

3. CONTROL AND ENERGY MANAGEMENT STRATEGY

The proposed approach for the energy management of the studied hybrid system relies on dynamics characteristics of the sources to share the power between the load, battery and SC.

Considering the low dynamics of the batteries, the proposed strategy suggests to keep the power provided by the battery constant. In that case, the load power variation is ensured by the SC due to its fast dynamics. The bidirectionality of the CLLC converter allows charging and discharging of the SC.

3.1. DC-BUS VOLTAGE CONTROL STRATEGY

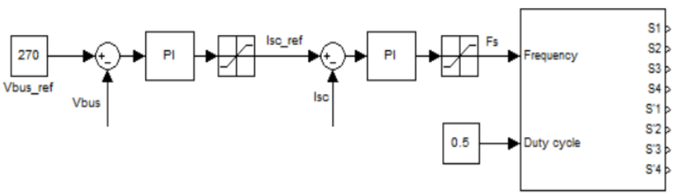

Fig. 5. DC-bus voltage control method

The control scheme is composed of two cascaded loops, where the outer loop controls the DC-bus voltage and the inner loop controls the SC current regarding the required load power. The control scheme is showed in Fig.5.

3.2. Control of the battery bank power

The batteries bank power control method is illustrated in Fig.6. The batteries power reference is fixed to its nominal value, then the reference current Ibat_ref is obtained in (8).

$$I_{bat\_ref} = \frac{P_{bat\_ref}}{V_{bat}} \qquad (8)$$

4. Simulation results

In order to validate the proposed configuration and energy management strategy for the hybrid system, a load power profile is applied as illustrated in Fig.7.

Fig.8 shows the batteries bank power. It can be seen that the power provided by the batteries is constant and it is not affected by the load power variations. In this way the batteries lifespan can be extended by reducing the dynamic stress and avoiding fast charging/discharging.

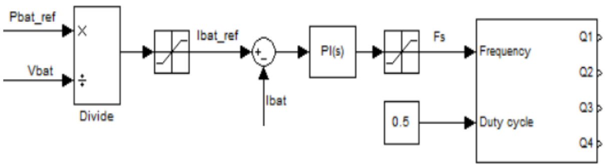

Fig. 6. Batteries pack power regulation method

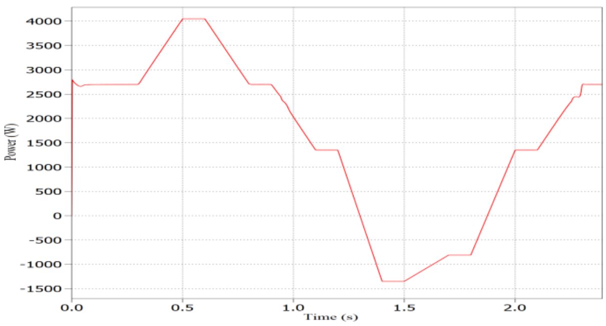

Fig. 7. Load power profile

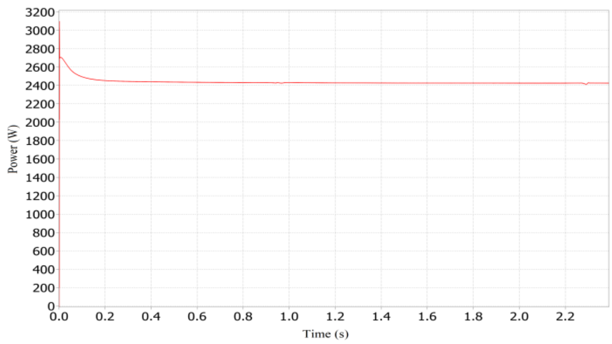

Fig. 8. Batteries bank provided power

Fig.9 shows the power provided by the SC. It is seen that all load fluctuations are ensured by the SC. In this study, the DC-bus voltage is fixed at 270V. Fig.10 shows the DC-bus voltage control result. It can be seen that the proposed method ensure the DC-bus voltage value at its reference.

Fig.11 shows the simulation waveforms of primary and secondary switches in forward mode. It is seen that primary switches can achieve ZVS, while secondary diodes work under ZCS conditions, and that is valid for all load conditions.

Fig.12 shows the simulation waveforms of primary and secondary switches of the LLC converter. It is seen that the energy transferred stays constant and the primary MOSFETs can reach ZVS for all the simulation time and the rectifier diodes achieve ZCS. So that efficiency and power density of the converter is enhanced.

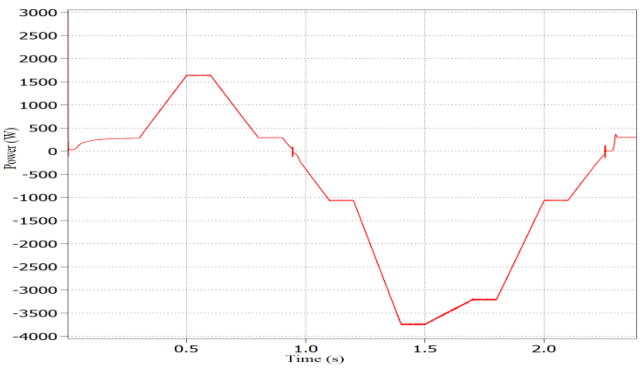

Fig. 9. Supercapacitors provided power

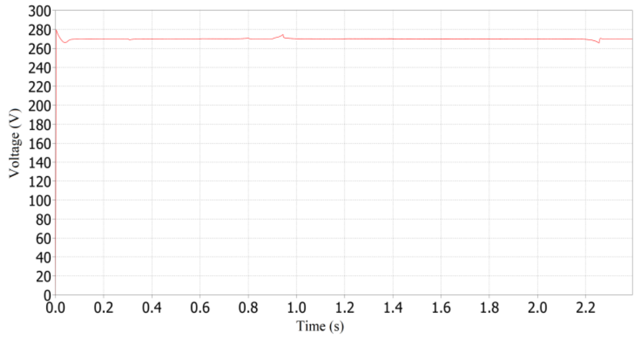

Fig. 10. DC-bus voltage

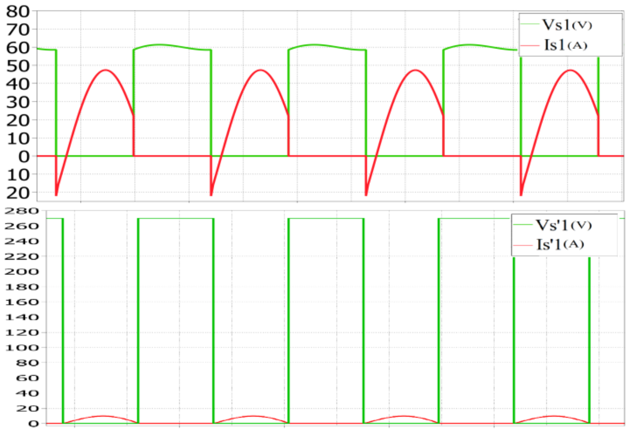

Fig. 11. Voltage and current waveforms of CLLC converter switches in forward mode

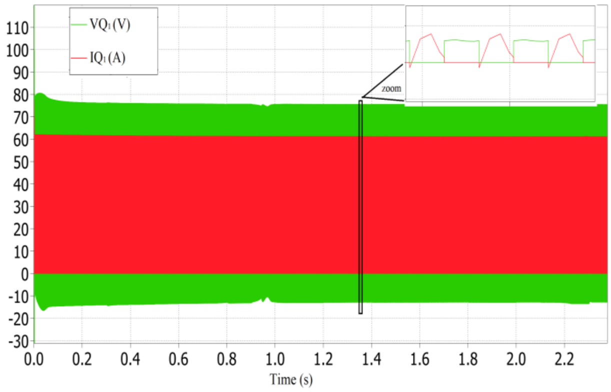

Fig. 12. Voltage and current waveforms of LLC converter switches

5. CONCLUSİON

This paper presents the utilization of isolated resonant DC/DC converters for a Battery / Supercapacitor hybrid system and proposes an energy management strategy to share the required power between the different sources and the load. The proposed energy management strategy is based on the dynamics of the sources to improve the lifespan of the battery bank. On the other hand, soft switching of the DC/DC resonant converters ensures the high efficiency and power density of the system.

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Sessions parallèles[1] (salles Centre d'Innovation)

13h20 : Session 2, chairman Florence OSSART (GeePs Sorbonne Université)

1. Reliable reserve balancing in a DC microgrid system under uncertainties, C. Kiebler, I. Prodan, F. Petzke, S. Streif, F. Stoican, Technische Universitat Chemnitz Automatic Control and System Dynamics Lab, LCIS INP Univ. Grenoble Alpes, UPB Department of Automatic Control and Systems Engineering Bucharest Romania
2. Local self-protection function for power line communication node in DC micro grid, T. K. Tran, H. Yahoui, D. Genon-Catalot, N. Siauve, N. Fourty, T. H. T. Ma, AMPERE Université Lyon 1, LCIS Grenoble Institute of Technology, Valence
3. DC Microgrids, H. Morel, P. Bevilacqua, G. Clerc, R. Delpoux, E. Dumitrescu, J.-Y. Gauthier, X. Lin-Shi, E. Niel, L. Pietrac, J.-F. Trégouët, AMPERE Lyon
4. Optimal real time management of droop-controlled microgrids, M. Legry, F. Colas, J.Y. Dieulot, C. Saudemont, L2EP Lille, CRIStAL Lille
5. Robust energy management optimization of a smart microgrid in day ahead markets, R. Bourbon, B. Sareni, X. Roboam, S.U. Ngueveu, LAPLACE CNRS Université Toulouse
6. Flatness-based hierarchical control of a meshed DC microgrid, I. Zafeiratou, D. V. A. Nguyen, I. Prodan, L. Lefèvre, L. Piétrac, LCIS INP Univ. Grenoble Alpes, AMPERE CNRS INSA Université de Lyon
7. Social acceptability of microgrids dedicated to electric vehicle charging stations, M. Sechilariu, F. Locment, N. Darene, AVENUES EA 7284 et COSTECH EA 2223 Université de Technologie de Compiègne

[1] Chaque présentation a une durée de 10 minutes pour l'exposé et 10 minutes pour les discussions

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Reliable reserve balancing in a DC microgrid system under uncertainties ⋆

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Stefan Streif ∗ Florin Stoican ∗∗∗

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Abstract: This work presents a robust MPC (Model Predictive Control) approach for reserve balancing in DC microgrid systems under uncertainties like wind power and energy price variations and different type of fault events. The robust MPC algorithm considers a shrinking prediction horizon which accounts for forecasts in energy price and renewable power over 1 day. Furthermore, a storage system is used to increase the utility of the demands and minimize the energy costs. The algorithm is tested in case of different types of faults affecting the system (line faults) and a reconfiguration algorithm is proposed in order to ensure the utility of demand.

Keywords: Robust MPC (Model Predictive Control), Energy management systems, DC microgrid, Fault events, Distributed energy resource

1. INTRODUCTION

In context of an increasing amount of renewable energy sources and political efforts to consume clean energy, an EMS (Energy Management System) is required to enable flexible power distribution depending on the available renewable energy. This goal of this work is to propose a robust optimization-based control implementation and reconfiguration for the reserve balancing in a microgrid system influenced by various types of uncertainties like wind and energy price variations or fault events.
The technical literature provides an extensive number of robust smart grids controller implementation with different goals. In (Prodan and Zio, 2014) a MPC algorithm for reliable microgrid energy management regarding uncertainties in the forecast is proposed and extended to fault cases in (Prodan et al., 2015). Herein the MPC algorithm considers soft constraints to enable feasibility under faults and disturbances. The algorithm enables robustness against one broken line (N-1 security). In (Wu and Conejo, 2017) the most critical facilities were protected to minimize the worst-case loads after physical attacks (faults), such that at least N-1 security is hold. Here a tri-level minmaxmin-problem is used, such that a planner try to minimize possible damages, the attacker tries to maximize the damage, while the operator handles the damage minimizing the cost. In (Khodabakhsh and Sirouspour, 2016) the battery usage is optimized, while a multi-variant Gaussian distribution is used to model uncertainties in energy price and demands. In addition (Wytock et al., 2017) proposed a scenario-based robust MPC approach, in which the worst case of all generated scenario is considered. (Khodaei, 2014) emphasis the resiliency for smart grid under islanded conditions, while in (Chen et al., 2016) the energy distribution of connected smart grids after natural distasters is concerned. Furthermore (Rahimiyan et al., 2014) provides an simple EMS and recorded data of energy price as well as wind power for 24 hours. An approximated minimax robust approach is proposed for improving the utility of demands under forecast uncertainties. Herein the approximation considers not all scenarios of disturbances. The present work extends the MPC implementation presented in (Prodan et al., 2015) and uses the data provided in (Rahimiyan et al., 2014) and further applies robust approaches and deals with fault events. The contributions of this work are summarized in the following:

- a robust economic MPC scheme with variable prediction horizon length will be implemented to handle profile variations and maximize utility;
- branch disconnects will be treated as faults to be attenuated via fault tolerant reconfiguration strategies;
- storage charge and discharge decisions will be customized such that a fault occurrence of finite length can be recovered from;
- stability in the nominal and under faulty functioning will be characterized in terms of set-theoretic notions.

⋆ Clemens Kiebler would like to acknowledge the financial suport of the Chair TRUST of Grenoble INP for his research stay at the LCIS laboratory, Grenoble INP, F-26000 Valence.

2. PRELIMINARY SIMULATION RESULTS

The microgrid architecture that we consider is take from Rahimiyan et al. (2014) and consists of 7 consumers, 5 buses, 1 main grid connection, 1 wind power supplier, 1 storage system and 6 lines.For the computation we use YALMIP and the solver Cplex with Matlab 2015. Here we compare the nominal EMS with the robust approach of the EMS and the minimax approach. For the comparison in table 1 we use the total utility (1), the total consumption (2), the battery usage (3), the number of discharges N_+° and charges N_-° and the profit (4). The latter describes the quality of control decision for one day.

$$u_{\text{total}} = -\lambda^{\text{peak}} P^{\text{S,max}} + \sum_{t=0}^{24} [\lambda^{\text{S}}(t) \sum_{i=1}^{N_{\text{S}}} e_i^{\text{S}}(t) + \lambda^{\text{G}} \sum_{j=1}^{N_{\text{W}}} e_j^{W}(t) - \sum_{k=1}^{N_{\text{C}}} u_k(t) e_k^{\text{C}}(t)] \quad (1)$$

$$e_{\text{total}} = \sum_{t=1}^{24} \sum_{k=1}^{N_{\text{C}}} e_k^{\text{C}}(t) \quad (2)$$

$$V_0 = \frac{\sum_{t=1}^{24} e^{\text{ST},-}(t)}{e_{\text{total}}} \quad (3)$$

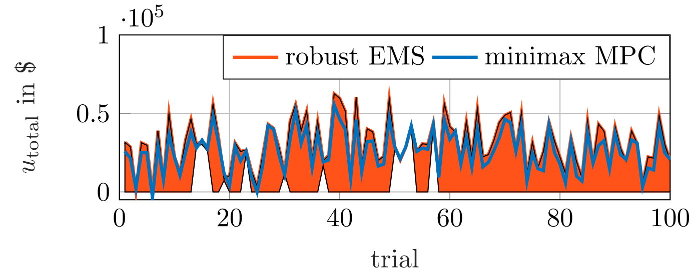
$$V_1 = \frac{u_{\text{total}}}{e_{\text{total}}} \quad (4)$$

For the nominal case in table 1 the highest total utility and profit is obtained for the nominal EMS, while the robust EMS and the minimax MPC indicate a higher battery usage und times of charge. Under nominal conditions the robust EMS produce a higher utility, consumption and profit than the minimax EMS.

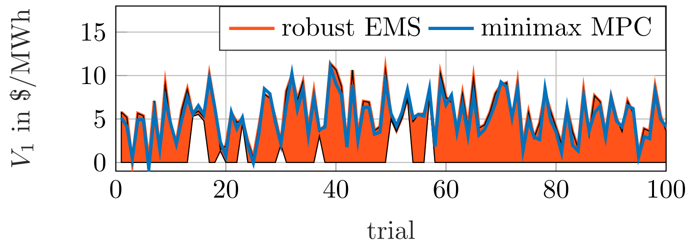
Table 1. Comparison between nominal EMS, robust EMS and minimax MPC

Approach	u_{total} [$]	e_{total} [GWh]	V_0	N_+°	N_-°	V_1 $/MWh
nominal EMS	$2.40 \cdot 10^4$	5.07	0.001	1	1	4.74
robust EMS 25% Γ_S, 0.5 Γ_W	$1.75 \cdot 10^4$	5.57	0.040	1	2	3.19
minimax MPC	$1.19 \cdot 10^4$	5.14	0.042	1	3	2.30

While we obtain infeasibility for the nominal EMS under disturbances, we want to analyse the performance of the robust EMS and the minimax MPC in extreme scenarios. Therefore we computed 100 scenarios, wherein the current available wind power and energy price takes the minimum or maximum forecast bound. The robust EMS determines different results depending on the robust parameters Γ^S and Γ^W Rahimiyan et al. (2014), hence we illustrate the full range of results. A value of zero in Fig. 1 indicates infeasibility for the robust EMS, while the minimax MPC is feasible for all trails. The maximum total utility and the profit in Fig.1 indicate a strong variability in the total utility depending on the trails. The minimax MPC is close to the maximum possible results of the robust EMS, in few cases even higher. Under minimax MPC consumers receive less energy, than the maximum possible consumption under the robust EMS. Note that robust MPC approximation used here makes some assumptions which (under certain circumstances) may lead to an infeasible problem.Thus, we consider that the minimax MPC which fully takes into account the profile variation bounds is better suited to the problem at hand (even, if it is more conservative and may thus not be the most optimal choice when compared with the nominal model).



(a) Total utility



(b) Profit

Fig. 1. Total utility and profit under minimax MPC and robust EMS for different robust parameters

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LOCAL SELF-PROTECTION FUNCTION FOR POWER LINE COMMUNICATION NODE IN DC MICRO GRID

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Abstract – In DC microgrid system, short-circuit and overvoltage can cause considerable damage to the power system elements. To ensure the functional safety of the grid, each communication node in the system is integrated the self-protection function with 2 layers of safety. In this research, we use relay as the main switch to isolate a node or a part of the grid from the rest of the grid.

Keywords – Self-protection, power line communication, DC micro grid, short circuit, overvoltage.

1. INTRODUCTION

Recently, the significant increase of the new distributed energy resources (DERs) based on renewable energy sources results in the development of DC micro grid applications. The protection for DC micro grid is one of the most important issues nowadays [1]. This paper presents the solution to disconnect a node or a part of the grid during the short-circuit or overvoltage event based on power line communication.

2. SELF-PROTECTION FUNCTION

2.1. DESIGN

The local self-protection funtion is shown in Fig.1. This system has 2 switches, S2 is directly controlled by microcontroller allowing the node to connect or disconnect to the grid and S1 automatically reacts when a problem happens by fastly sensing the voltage of the line or through a current sensor (first layer). S1 can also react when receiving a emergency signal from others through microcontroller.

2.2. OPERATIONAL PRINCIPLE

The operation of this system is shown in Fig. 2. When there are no errors from the node itself, the switch S2 will close. Otherwise, it will open. The switch S1 will open when the comparator or the sensor detect a problem or when the node receive the error signal from others.

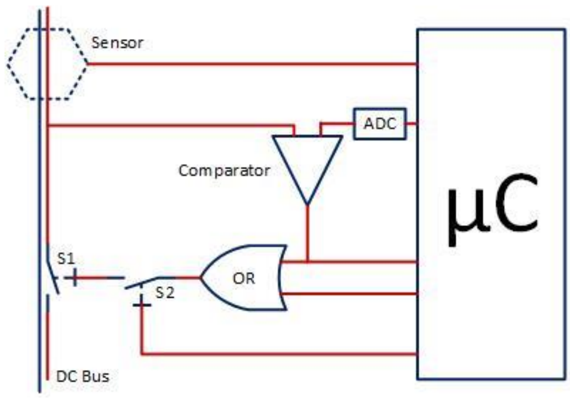

Fig. 1. Schematic for battery management system

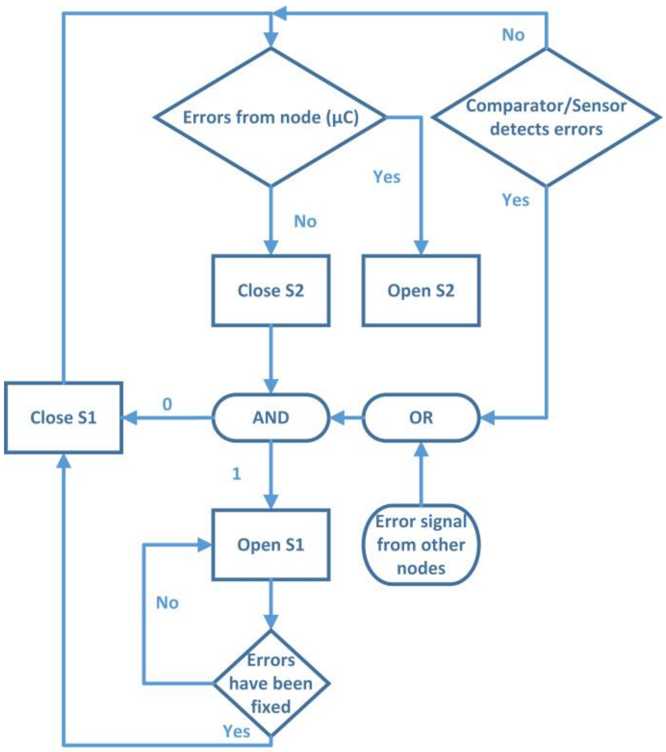

Fig. 2. The operation of the self-protection function

2.3. EXPERIMENTAL RESULTS

In order to validate the proposed solution, a prototype has been build using microcontroller Tiva C from TI. The reaction from overvoltage and short-circuit condition are shown in Fig.3 and Fig. 4, respectively. YELLOW is node voltage and BLUE is bus voltage. In overvoltage test, we limit the overshoot voltage at 27V. In shortcircuit test, we use the 7V DC bus. The relay take less than 1ms to completely disconnect in overvoltage case and less than 5ms in shortcircuit case.

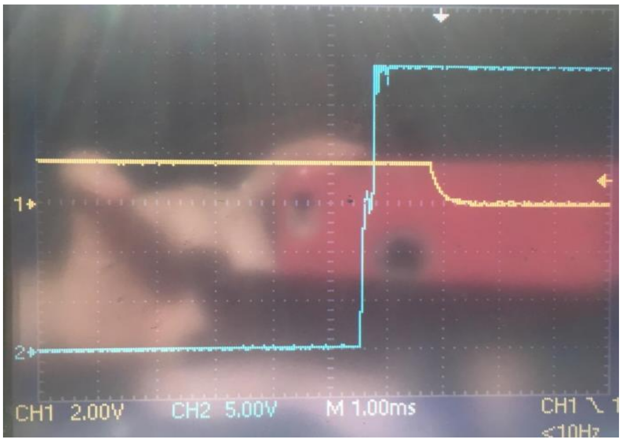

Fig. 3. Overvoltage test

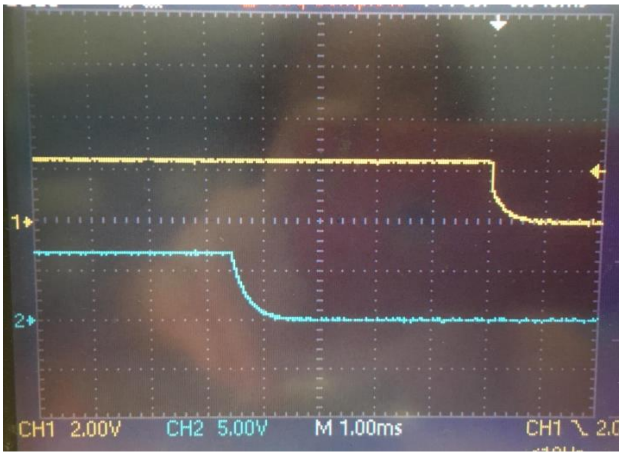

Fig. 4. Short-circuit test

3. CONCLUSİON

This paper presents the operational principle, design considerations and experimental results of the self-protection solution based on PLC technology. This solution is designed to take advantage of an existing wire infrastructure. In the future, we will investigate other switch kinds to increase cutting time of the system.

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DC MICROGRIDS

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Abstract – Les microréseaux sont des réseaux électriques à faible échelle, comme celle d'un bâtiment, voire d'un quartier, ou encore celle d'un système embarqué. Aujourd'hui, l'essentiel des travaux sur les microréseaux concerne les microréseaux AC, surtout en France. Cela résulte de l'existence de nombreuses infrastructures et normes. Le déploiement des réseaux DC est aussi en forte progression dans l'embarqué (avionique, véhicule électrique, etc.). Le contrôle robuste de ces nouveaux systèmes est un enjeu scientifique et sociétal. Les microréseaux DC sont aussi une voie d'analyse à moindre coût pour étudier les futurs réseaux MVDC des métropoles. Pour toutes ces raisons, le laboratoire Ampère développe des activités de recherche, pour l'essentiel, nouvelles, dans le domaine des microréseaux DC.

Keywords – DC microgrid, contrôle, MVDC.

1. INTRODUCTION

Les microréseaux sont des réseaux électriques à faible échelle, comme celle d'un bâtiment, voire d'un quartier, ou encore celle d'un système embarqué. Aujourd'hui, l'essentiel des travaux sur les microréseaux concerne les microréseaux AC [1], surtout en France. Cela résulte de l'existence de nombreuses infrastructures et normes.

Le déploiement des réseaux DC est aussi en forte progression dans l'embarqué (avionique, véhicule électrique, etc.). Le contrôle robuste de ces nouveaux systèmes est un enjeu scientifique et sociétal. Les microréseaux DC sont aussi une voie d'analyse à moindre coût pour étudier les futurs réseaux MVDC des métropoles.

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2. MICRORÉSEAUX DC MAILLÉS

Les microréseaux DC, sont des alternatives prometteuses aux réseaux de distribution AC classiques notamment pour l'intégration des énergies renouvelables [2], [3]. Ils permettent par exemple de réduire la consommation d'énergie de 25 % lors de l'alimentation directe d'immeubles tertiaires par des panneaux photovoltaïques [4].

Nous développons de façon plus originale des microréseaux maillés DC. L'intérêt supplémentaire des réseaux maillé par rapport à des réseaux radiaux est la réduction de la quantité de conducteur nécessaire pour alimenter un bâtiment notamment tertiaire [6].

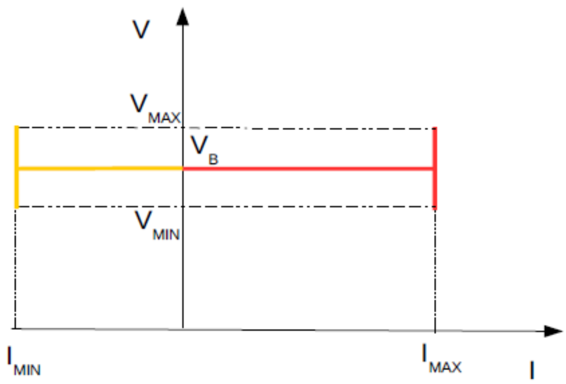

Fig. 1. Stratégie de contrôle des sorties des smart-nodes en régime établi dans le plan courant-tension.

Naturellement, l'obstacle économique est réel en Europe compte tenu du fort niveau d'équipement en réseaux de distribution AC. De plus des verrous scientifiques existent. Pour un microréseau DC et maillé, la surveillance des niveaux de courant transmis dans chaque ligne est critique, notamment au niveau de la sécurité. Le contrôle des flux d'énergie (courant ou puissance) est donc nécessaire [7]. Nous avons développé une stratégie basée sur l'utilisation de smart-nodes assurant le contrôle des flux associés à une stratégie de contrôle polyvalente [5].

Enfin, la protection des personnes et des biens doit être définie avec précision. La coupure DC est une difficulté, surtout en haute tension. Comme d'autres, nous pensons que la protection doit être intégrée aux convertisseurs.

Finalement, un réseau maillé DC a de nombreux avantages de structure comme :

- un besoin en masse de conducteur plus faible,

- une redondance de câblage permettant une meilleure
- disponibilité de l'énergie en cas de panne d'une source ou d'un nœud,
- une flexibilité accrue, par exemple en insérant ou en déplaçant des sources ou des charges.

Dans le cadre du projet ANR/C3µ et du CPER/GD3E, un prototype de microréseau DC maillé a été développé (Fig. 2). Nous travaillons sur l'optimisation de la stratégie de contrôle des courants dans les différentes branches du réseau. Pour cela nous pouvons utiliser des *control-flow converters* Fig. 2.

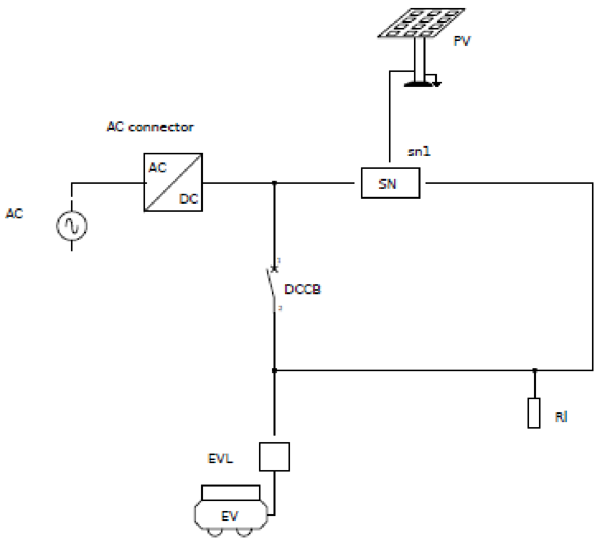

Fig. 2: Maquette visée dans nos projets. Le smart-node (SN) est prévu pour assurer 20 kW par branche.

Dans le cadre du projet GD3E, nous avons eu l'occasion de développer une plateforme temps réel basée sur la solution OPAL-RT.

Cette plateforme nous permettra aussi de tester des solutions de Power in the loop (PHIL), en pilotant un smart-node via le banc OPAL-RT, inséré dans la maquette C3µ (Fig. 2).

3. COMMANDES ROBUSTES POUR LES RÉSEAUX

Le déploiement de nombreux réseau à courant continu a vite posé le problème du besoin de méthodologie de commandes performantes et robustes pour s'adapter à la complexité des situations. Parmi ces situations, la mise en parallèle de charges et des sources est fréquente dans les systèmes embarqués. Le laboratoire Ampère a étudié certaines configurations et a testé des stratégies de contrôle robuste.

4. COMMANDES DE MICRORÉSEAUX DC

En sein du Laboratoire Ampère, les travaux du groupe de travail Automatique pour l'Electronique de Puissance (APEP) s'inscrivent dans ce cadre en mettant l'accent sur la commande de convertisseurs DC/DC en parallèle, mimant la topologie d'un réseau DC maillé rudimentaire. Cette topologie est similaire à celle des convertisseurs multi-phases qui sont principalement utilisés dans le but de réduire l'ondulation de sortie par l'entrelacement des Modulations de Largeur d'Impulsion (MLI). Par ailleurs, cette interconnexion permet également de définir la politique de répartition de flux de puissance entre les différentes branches des convertisseurs. En effet, si la régulation de la tension de sortie impose le courant global, la distribution de courant dans les branches reste libre. La stratégie la plus répandue pour faire face à ce degré de liberté, dans le cadre de convertisseurs en parallèle, est le partage de courant dit équilibré qui répartit uniformément les courants entre branches.

Une des contributions a été de montrer qu'en général, la répartition de courant équilibrée n'est pas optimale concernant les pertes de puissance lorsque les convertisseurs sont hétérogènes. Motivée par cette observation, une nouvelle loi de commande optimisant la répartition de courant a été proposée dans [9] et [10]. Ce nouveau contrôleur est conforme aux schémas classiques (application du principe de séparation fréquentielle) de telle sorte que la répartition de courant est réalisée par la couche de commande secondaire. Les travaux plus récents ont montré que la séparation fréquentielle (bande passante de la distribution de courant plus étroite que celle de la régulation de tension) pouvait être évitée en considérant une décomposition géométrique des espaces d'états et d'entrées ([11] et [12]) et ainsi atteindre de meilleures performances. Ces résultats ont également été réinterprétés en considérant le formalisme Hamiltonien [13]. Ces travaux ont permis d'engager une collaboration avec Marc Bodson, Professeur à University of Utah, Salt Lake City.

Une des perspectives est d'appliquer ces nouvelles méthodologies sur des modèles traduisant plus fidèlement la dynamique des microréseaux DC.

5. ÉVÉNEMENTS DISCRETS ET RÉSEAUX

Les réseaux électriques modernes impliquent des convertisseurs et des dispositifs de sécurité. Cela conduit au besoin de protocoles des gestion d'événements (démarrage, ouverture, court-circuit, panne …). Ces protocoles réalisent des stratégies de reconfiguration et se matérialisent par des séquences d'actions de reconfiguration :

- des changements de mode de fonctionnement au sein d'un ou plusieurs nœuds ;
- un changement d'interconnexions à une échelle plus ou moins étendue du réseau, en réponse à un événement critique.

Ces séquences de reconfiguration doivent la plupart du temps répondre à une logique globale, reflétant des exigences soit qualitatives, de cohérence ou de réactivité à un événement critique, soit quantitatives. L'architecture par nature décentralisée du réseau requiert quant à elle une mise en œuvre locale de chaque logique de reconfiguration globale, comme illustré dans la Figure 3.

Au-delà d'une élaboration manuelle, une stratégie de reconfiguration peut être générée automatiquement, sous forme d'un superviseur, à partir d'un modèle reflétant le comportement des nœuds du réseau et de l'expression d'une exigence qualitative et/ou quantitative. La technique de synthèse par supervision [14] est aujourd'hui mature pour cela. Cependant, l'obtention d'une logique de contrôle distribuée localement reste aujourd'hui un verrou scientifique important. Des travaux sont menés au sein du laboratoire Ampère, en vue de l'obtention de superviseurs distribués et communicants, assurant une cohérence globale au niveau du réseau. Ces travaux se sont déroulés au sein du projet Supergrid [15] d'une part, avec un applicatif en réseaux électriques, et indépendamment, avec un applicatif dans le domaine des réseaux de capteurs [16].

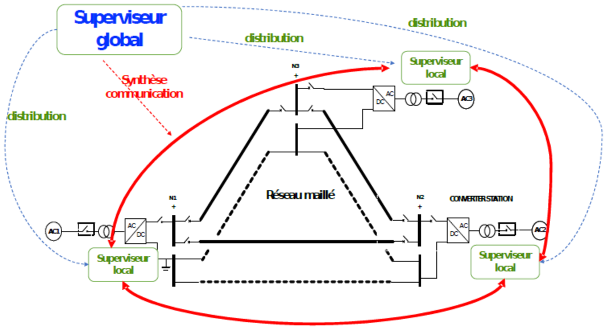

Fig. 3. Génération et distribution de superviseurs communicants.

Un objectif sera à terme de mettre en œuvre une supervision décentralisée comme le fait Ethernet pour la gestion des flux d'information dans les hubs.

6. CONCLUSION

Ces thématiques sont assez nouvelles au laboratoire Ampère même si historiquement celui-ci avait été impliqué dans les réseaux de transport en haute tension AC. Aujourd'hui plusieurs projets et des équipements ont permis d'afficher un nombre significatif d'intervenants.

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OPTIMAL REAL TIME MANAGEMENT OF DROOP-CONTROLLED MICROGRIDS

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Abstract – This paper proposes to optimize the real time operation of a microgrid controlled two-layer Model Predictive Controller supervisor. Based on the classical decomposition of control level, the proposed supervisor tracks long-term economic references from a classical economic optimization routine. It uses the different power and voltage references as levers to reach this optimum and maintain the state of the microgrid within limitations. In addition, it is able to minimize the grid losses.

Keywords – Microgrids, Predictive Control, Hierarchical control, Optimal control, Power Management System.

1. INTRODUCTION

Microgrids can be defined as a set of distributed generators, renewables or conventional ones, storage systems and loads that can operate in a coordinated manner and possibly in islanded mode. In addition, their aim is to produce locally what is needed locally, by means of local controllers. Based on conventional power system representation, the microgrid community has developed three-level structure control supervisor (Figure 1).

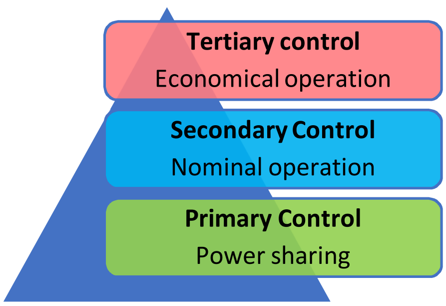

Figure 1: Microgrid control architecture

The primary control at the faster layer ensures the power sharing between all the active generators through well-known techniques as classical droop control and its variants [1]. The secondary control aims to restore nominal operations of the microgrid following any fluctuation of the load or renewable sources while minimizing losses or the operating cost. Finally, the tertiary control mainly focuses on the economical optimization of the microgrid on a long-term basis. Secondary and tertiary control are also known as Power and Energy Management System (EMS and PMS), respectively.

Each layer embeds a detailed model of the dynamics of interest to optimize specific criteria. However, the convergence of each objective may not be ensured. Coordinating economic constraints with real time operations is crucial for microgrid control.

The focus on multi-layer structure for microgrid supervisor are mainly motivated to provide a solution to stochastic and uncertain forecast, as explained in [2] and [3]. However, the model and objective function remain the same in each layer. In [4], the author suggested to use a multi-layer structure so that each layer includes different model dynamics and objectives. Among the three proposed architectures, the most promising consists in a steady state optimization followed by a target correction at the lower layer side that can handle an additional task. It can be upgraded to take advantage of the latter opportunity, and to include a tracking controller.

The novelty of this supervisor is twofold. First, the Model Predictive Control (MPC) technique allows the supervisor to include a trajectory tracking problem into the objective function and thus to consider economic references. Second, the embedded model is able to predict the power injections at each node of the microgrid and, by upgrading the objective function, losses can be minimized.

2. MPC-BASED SUPERVİSOR AND MİCROGRİD MODELLİNG

To develop the proposed supervisor, we used the well-known Model Predictive Control technique which allows to capture the future behavior of the system thanks to a prediction model and, next, to minimize a multi-objective function with multiple dynamics. The use of a two-layer MPC supervisor replicates the conventional hierarchical control of microgrids. On the longer timescale, an economic optimization is achieved for at least one day ahead. Model and constraints of this layer only include the slow dynamics of the equipment and each individual economic performance. On the faster timescale, the cost function embeds a trajectory tracking problem and additional objectives related to the microgrid operation, such as losses minimization, voltage and frequency deviations. The global objective function can be expressed as:

$$\min_{\Delta u} J = \sum_{k=1}^{Nc} \left[\alpha \left(\tilde{x}(k) - x^*(k) \right)^2 + \beta \left(\Delta u(k) \right)^2 + \lambda \left(P_{losses} \right)^2 \right] \quad (1)$$

In which α, β and λ are the weighting factors of the trajectory deviation, the control effort and the losses resp., $\tilde{x}(k)$ and $x^*(k)$ are the predicted and reference states for time k. It can be noticed that an additional objective is added to prevent levers saturation.

The optimization problem solved by the supervisor is formulated as a MIQP (Mixed Integer Quadratic Program):

$$\min_{\Delta u} J = \sum_{k=1}^{Nc} \left[\alpha \left(\tilde{x}(k) - x^*(k) \right)^2 + \beta \left(\Delta u(k) \right)^2 + \lambda \left(P_{losses} \right)^2 \right] \quad (2)$$

Subject to the microgrid dynamics:

$$X(k+1) = \mathbf{A}.X(k) + \mathbf{B}.\Delta U(k) + \mathbf{C}.\Delta D(k)$$

and subject to the limits of each equipment.

Matrices **A, B** and **C** represent the dynamics of the microgrids, the dynamics of the control inputs and the disturbances respectively. $X(k+1)$ is composed of the States of Charge, voltage nodes and angles, the frequency, the active and reactive power references, and the active and reactive power injections for each node at the timestep k. ΔU represents the decision variables: active and reactive power references deviations and the voltage references deviation of the droop-controlled inverters. Finally, ΔD is the vector of disturbances that takes the loads and the renewables sources into account.

3. Simulation Results

A thorough design of the economic references is out of the scope of this paper, and only a simple deterministic economical optimization from load and production profiles has been performed. The proposed supervisor has been implemented in MATLAB with the toolbox YALMIP [5].

The simulations will focus on the improvement of the real time operations of a microgrid and feature two test cases. In the first one, the line losses are not included in the objective function. This means that one of the storage devices will behave as a slack node and impose the voltage. The second one includes the line losses and aims to prove the effectiveness of the supervisor. Figure 2 represents the single line diagram of the microgrid for the test cases. It is based on rated power of 100 kW PV productions and 100kW/500kWh storage devices. The results for test case 1 are presented in Figure 3, with a voltage profile of each node and the line losses curve. It can be seen that the voltage fluctuates due to the load and PV production variations and induces higher losses when the storage systems are charging.

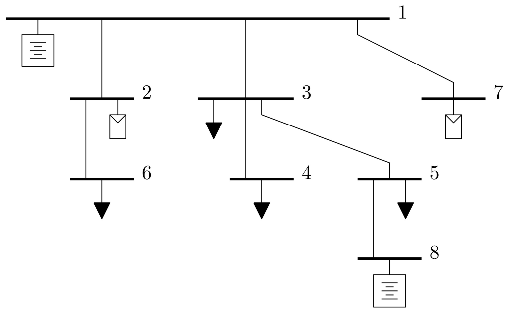

Figure 2: Microgrid test feeder

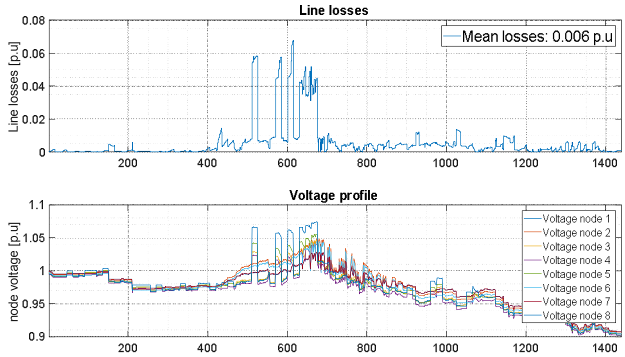

Figure 3: Test case 1. Supervisor without line losses minimisation

It is expected that the improved supervisor will reduce the line losses while maintaining the microgrid characteristics within boundaries. Another point of attention is the computation time required for both supervisor so that it could be use in real time with larger microgrids.

Theses points will be further detailed in the final paper with complete simulation results of the microgrid for both cases.

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Systèmes d'Énergie Électrique dans leurs Dimensions Sociétales - GdR 2994

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Robust energy management optimization of a smart microgrid in day ahead markets

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Abstract - This paper aims at designing a robust optimization for the exploitation of a smart microgrid composed of wind turbines coupled with an Energy Storage System (ESS). This study faces a standalone electric microgrid problem in the context of day ahead markets; a techno-economical point of view including storage cost evaluation, commitment failure penalties and exploitation gains is proposed to optimize the ESS. A two stage "cascaded" optimization process is used integrating a Mixed Integer Linear Programing (MILP) as the inner loop for the energy management of the ESS coupled with a Non Linear optimization for the outer loop which sets the power commitment.

Keywords – Day-ahead markets, optimization, robustness, smart microgrids, energy management.

1. Introduction

The integration rate of renewable energy sources is one key issue of our modern society. Utilization of EES coupled with renewable sources such as wind turbines in a smart microgrid seems to be one of the solutions to this issue [1]. Adapted production requirements are used in such smart microgrids and are focused on two aspects in particular: The day ahead production power commitment and the FIT variation during the day. Our proposal faces this issue through a cascaded loop of optimization. The outer loop has to set the level of the power commitment taking account of both the power forecast and the FIT per hour. For each commitment generated by this loop, the inner optimization loop uses a MILP algorithm to solve the current day EES management (P_{ees}).

2. Problem Setting

The FIT variation used is this case study is quite simplistic and extracted from a CRE's tender (Commission de Régulation de l'Electricité). The FIT is kept constant during all day and a fixed bonus of 200 €/MWh is added during the 19h-21h peak power demand. A tolerance layer is superposed to the day ahead commitment power and if the power sent to the grid is out of the tolerance layer the energy transferred to the network is not paid. A linear power flow model is used to manage the MILP[1] . The external loop has to determine the commitment power (P_{com}) and the internal loop has to keep the grid power (P_{grid}) inside tolerance layer. During this optimization the input data are only the one available one day ahead to determine P_{com}. A virtual power production during the D day is generated to run the second inner loop of optimization.

3. Optimization

N virtual production powers P_{prod} are generated which respect to the Laplace distribution and the autocorrelation of the original data [2]. The global cascaded optimization process is displayed in Fig. 1.

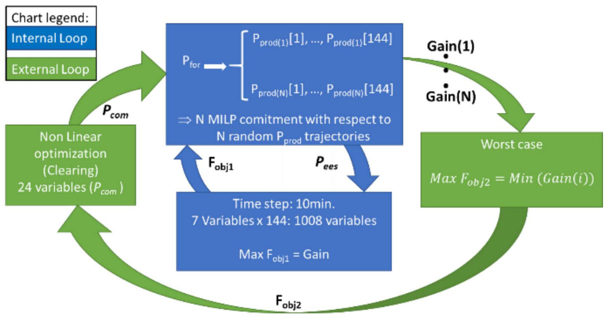

Figure 1:Double step robust optimization process

This simulation is set for one day, but the constraints added to our problem allow us to run several days by assembling the data.

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Flatness-based hierarchical control of a meshed DC microgrid

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Abstract: This paper proposes a meshed DC microgrid architecture supervised by a multi-layer optimization based control to handle the load balancing problem for the proper energy distribution within the transmission network. The control architecture is implemented via a combination of flatness and MPC (Model Predictive Conctrol). This work deals with the first two layers and validates the proposed approach in simulation over a DC microgrid consisting of a collection of solar panels (180 W peak PV generation), an energy storage system composed by lead acid batteries (165 Ah battery capacity), a utility grid (4200 W maximum UG generation) and a group of interconnected loads (3440 W peak demand).

Keywords: Meshed DC microgrid, Differential flatness, B-splines parametrization, Power balancing, Model Predictive Control

1. INTRODUCTION

Recently, the increasing demand on energy consumption in buildings (residential, commercial, industrial) requires flexibility and efficiency on the energy generation. The main grid cannot offer energy independence and does not ensure the continuity of the power transmission. As a consequence the interest on microgrids has increased due to their high reliability when different distributed energy ressources (DERs) are integrated into a power system (Wang et al., 2012). Moreover, the interest on DC microgrids tends to grow as a result of the constant development and production of the DC equipment both for renewable sources (e.g. solar panels (PV)) and loads (e.g. electrical vehicles (EV)).

The following work presents a DC microgrid architecture, as shown in Fig. 1 with a meshed topology, signifying that the power generation is a result of a collection of DERs (utility grid-UG, solar panel-PV, storage facility-ES) and passes through multiple possible paths until it reaches its final point. Consequently, a possible interruption of the power transmission can be avoided and the constant and safe operation of the system can be ensured. The aforementioned components in combination with their topology result in a strongly nonlinear system, distributed in space and in time. The global system dynamics is separated into different timescales. Primarily, the existence of the DC/DC converters creates a fast dynamics which needs to be stabilized around a set-point. Secondly, the slow dynamics is related to the battery and the PV system. At the same time, we have to cope with variable profiles and costs and obey to a set of constraints related to the different characteristics of the system components like the battery's capacity or the permissible UG power.

The microgrid energy management problem is generally formulated as a constrained optimization problem in continuous time, not straightforward to solve. In the literature, there are several methods proposed for the modeling and control of such systems. Because of their complexity, most of the times, they propose a simple dynamics in order to proceed to its supervision (Wang et al., 2012). Furthermore, there are researchers that look into multi-layer approaches where the generated profiles may do not fully respect the constraints or the dynamics of the system. Various works concentrate on the use of MPC in combination with mixed-integer programming for battery scheduling or chance constraints to deal with profiles uncertainties (Velarde et al., 2017). The hierachical implementation of MPC is discussed in (Velarde et al., 2017) for microgrids operating in islanded mode. A two-layer control and coordination for DERs is addressed in (Drgoňa et al., 2018) through the use of MPC via machine learning.

This paper builds upon our previous results where a port-Hamiltonian (PH) model (Zafeiratou et al., 2018) was developed for each component of the DC microgrid. In here, we go further in i) developing a flat representation of the strongly nonlinear interconnected system and ii) dealing with the optimization-based control of the global meshed DC microgrid. We propose a three layer control where:

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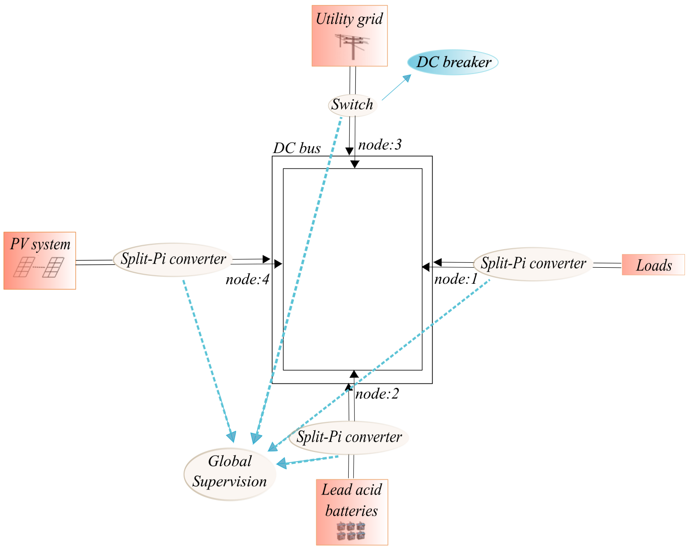

Fig. 1. Meshed DC microgrid architecture.

- at the *higher level* we generate optimal reference profiles using the differential flatness notion with the B-splines parametrization,
- at the *middle level* we use an MPC (Model Predictive Control) problem which is formulated to track the profiles under perturbations,
- at the *lower level* we control the switching activity of the DC/DC converters for the voltage regulation.

2. MULTI-LAYER OPTIMIZATION

2.1 General architecture

The main goal is to minimize the electricity cost by minimizing the energy consumption from the UG, hence taking advantage of the PV power production and the ES system capacity. The control variables within the DC microgrid system are: the duty cycles $d_{1sc}(t)$, $d_{2sc}(t)$ of the Split-Pi converter and the UG power $P_{ug}(t)$. Gathering all the elements, we present hereinafter the control approach (illustrated in Fig.2) we propose:

- at the *high level* we use the flat representation of the Split-Pi converter and the battery system, as in Appendix A, and generate optimal reference profiles for the battery current and voltage, denoted as i_b and v_b respectively. At the same time, we take into account the system dynamics and the continuous-time constraints validation.
- at the *middle level* we use the a priori given profiles and track them in a constrained MPC framework.
- at the *low level* we control the duty cycles of the DC/DC converters, considering the tracking profiles obtained from the MPC controller in the middle level.

2.2 Simulations

In this subsection, we present two simulations that were held in the high and the middle level concerning the power balancing problem. In Fig. 3 we obtain the optimal reference profiles within the high level control framework and in Fig.4 we track the aforementioned profiles by taking into account disturbances.

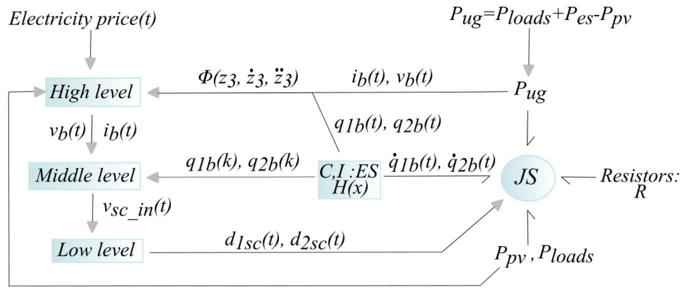

Fig. 2. Hierarchical control scheme of the DC microgrid.

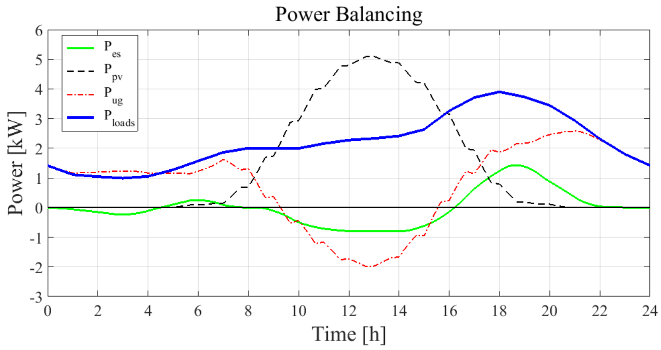

Fig. 3. Power balancing optimal reference profiles.

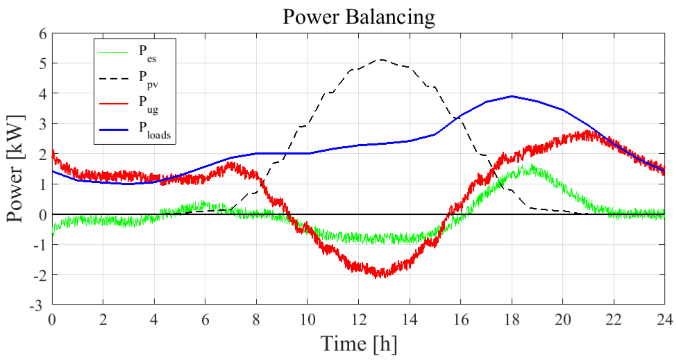

Fig. 4. The power balancing tracking profiles under perturbation.

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SOCIAL ACCEPTABILITY OF MICROGRIDS DEDICATED TO ELECTRIC VEHICLE CHARGING STATIONS

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***Abstract*—**The electric mobility requires installing recharging infrastructures for electric vehicles (EVs) in urban areas. This paper aims at: (i) presenting an innovative energy system and (ii) at highlighting the social acceptability of microgrid powered EVs recharge station. The proposed energy system consists of three components: an intelligent infrastructure for recharging EVs (IIREVs) powered by microgrid, a heterogeneous fleet of EVs, and a building with a connection to IIREVs. The microgrid optimizes the power flows in accordance with the requirements of the EVs users and the public power grid. This microgrid contains photovoltaic sources and takes into account the following strategies: vehicle to grid, vehicle to building, and IIREVs to building (energy generated by the IIREVs and not used by the EVs directly feeds the building). This paper focuses mainly on social acceptability and highlights an action plan according to user expectations of IIREVs best fitting in urban areas. The survey results show that the IIREVs are accepted socially by a large majority while some imperatives must be considered in the urban cases implantations.

Keywords— social acceptability; electromobility; microgrid; renewable energy; electric vehicles;.

1. INTRODUCTION

The transition to low-carbon urban mobility [1] requires expansion of electric vehicles (EVs). However, the EVs recharge increases the power call in real time. Due to the high current required, and depending on when and where the EVs are connected, the charging stations cause problems and constraints for the power grid [2]. The indirect pollution created by charging stations depends on the energy mix of electricity production allowing peak consumption, *i.e.* the spinning reserve composed mainly of fossil fuel-based power plants. In order to respond to EVs recharging, this spinning reserve should be expanded. Moreover, with regard to users, their preference to recharge the EVs is usually at the appropriate time rather than out of peak periods [3]. Thus, starting from a certain total power demand, representing the recharge of EVs during the day period, the power grid could be strongly affected [4]. This paper aims at presenting an innovative energy system for EVs charging station, based on renewable energy, highlighting its social acceptability. The section 2 introduces the microgrid powered recharge station for EVs while the section 3 presents the social acceptability survey and the obtained results. Finally, conclusion and further works are given in the last section.

2. MICROGRID POWERED EVS RECHARGE STATION

The innovative energy system is defined as a set of objects: an intelligent infrastructure for recharging EVs (IIREVs) powered by microgrid, a heterogeneous fleet of EVs, and a building having a connection to the IIREVs. The goal is to provide IIREVs in urban areas while facilitating interactions between IIREVs, the power grid, users of EVs, and surrounding building. The EVs taken into account in this study are the electric cars, the two-wheeled EVs, and other mobility devices including mini-motorcycles, *e.g.* electric scooters and electric unicycles. The IIREVs is based on a smart microgrid [2] that optimizes the power flows in accordance with the requirements of the public power grid [5]. This energy system is able to manage optimized power flows and takes into account the following strategies: vehicle to grid (V2G), discharge of EVs batteries into the public grid; vehicle to building (V2H), discharge of EVs batteries into building; IIREVs to building (I2H), electrical supply of building by IIREVs. Figure 1 presents these interactions.

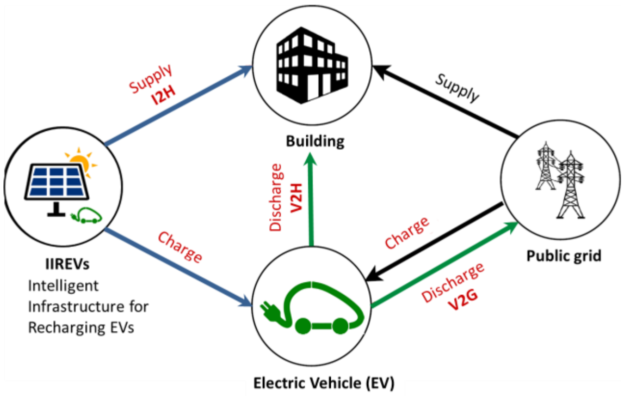

Figure 1. Innovative energy system and its objects interactions.

V2G smooths the peaks of consumption at the power grid level; V2H smooths the peaks of consumption at the building level secures the building supply during an electrical cut-off; I2H implies that IIREVs supplies the building if no EV needs energy. One of the solutions can be the microgrid integrated in the car parking where PV panels are installed on sun-shading roofs as shown in Fig.

2. This microgrid contains photovoltaic (PV) sources, electrochemical storage, supercapacitors, connection to the surrounding building, and connection to the public grid [6].

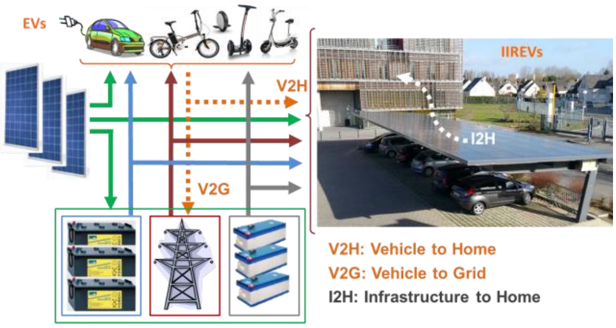

Figure 2. IIREVs of UTC Compiègne.

Nowadays PV integrated car parking shades exist, but inject the total produced energy into the public grid and the V2G mode is used to compensate for the intermittent nature of PV energy. The control algorithms are not optimized and only take into account the state of charge of the EVs batteries. Moreover, there is not a technical-economic optimization algorithm; constraints related to the use of the power grid are not taken into account and interfacing with the end-user is not provided. However, several works deal with the possibility of using the V2G mode to participate in ancillary services. Often, within the limit of the possible discharge threshold, EV is seen as a conventional energy reservoir for setting the frequency. Some publications are focused on the generation of reactive power; furthermore, the use of EVs connected to charging stations is related to the whole city or larger areas and less often to a specific urban neighbourhood or defined local urban area. However, in the absence of a proposal of a smart microgrid dedicated to the EVs recharging, the I2H strategy is not proposed.

3. Social acceptability survey

This paper follows the three phases that were conducted for the realization of this acceptability survey [7]. As a first step, the marketing and societal survey defines the product IIREVs, the market, and the actors [8]. In a second step, the qualitative survey carried out on a limited sample of people lists their reflections on the IIREVs object. Thirdly, the quantitative questionnaire aims to obtain a large amount of opinion on the project. At the end of the study general trends on the IIREVs project and an action plan are highlighted.

3.1 Marketing and societal survey

In order to produce an adapted questionnaire and thus to obtain data allowing reflection on the IIREVs and its feasibility, the typology of innovation must be defined. Concerning the IIREVs, two innovations can be distinguished: the charging of EVs using PV energy and the V2G / V2H strategies. The PV-integrated microgrid, which powers the EVs charging station, represents an incremental innovation in relation to a range of existing PV-integrated car parking shade or to a gas station for thermic vehicles. In contrast, the V2G / V2H strategies represent disruptive technologies. In addition, one note that the IIREVs connects a multitude of actors including the existence of a triple consumer (EV user, building owner, public grid) whose opinion is to be assessed in the rest of this work.

3.2 Qualitative survey

The qualitative survey is based on a questionnaire addressed to a panel which implies the diversity of ages, of socio-economic classification, and of type of used vehicle (thermic or electric). The qualitative capture of the reactions was based on the completion of a very open questionnaire in order to make the speakers talk about their own practices and to become familiar with certain trends to analyze without influencing the answers. It was not only about knowing how to talk to people but also about being sensitive to how they could describe their activities. This qualitative inquiry was also necessary to allow unexpected expressions to be expressed and to identify points of view.

3.3 Quantitative survey

To formalize the quantitative questionnaire, the formulation of the social acceptability, the marketing and societal approach, and the answers to the qualitative questionnaire were deeply analyzed [9]. The main points taken into account for the quantitative questionnaire writing are: travel habits of users; current obstacles to the electromobility development; influence of ecology on the project acceptability ; main expectations of users regarding IIREVs; strategic locations for IIREVs locations; public institutions or private companies that should own the IIREVs; users opinion about the potential partial EVs discharge; users opinion about the recharge by PV; users opinion about the to the city car parking shades, including their visual urban landscape integration.

From these points, 33 questions were written. For each question, the most appropriate and relevant types of responses for the subsequent exploitation of the results were determined. In the first part of the questionnaire, the subject is explained in a simple and concise way to facilitate the understanding of IIREVs and the questions. General questions to know the profile of the user are given at the beginning, and then followed questions about the IIREVs and the system discharge-recharge. Finally, the questionnaire ends with the PV recharge and the implantation of the car parking shades. The diffusion of the questionnaire was carried out by the following means of communication: weekly newspaper of UTC, Tremplin UTC, social networks such as LinkedIn, Twitter, Facebook, and personal emailing). The town council of Compiègne and its suburbs distributed the survey among the inhabitants by publishing the link on their Facebook account. Within two weeks, 629 answers were obtained.

According to figure 3, the panel's analysis, reveals a diverse economic classification. However, the 15-25 age group (figure 4 (a)) and the "student" socio-economic classification (figure 3) are overrepresented due mainly to the dissemination of the questionnaire. Nevertheless, the "student" overrepresentation is not problematic in this study because it allows knowing the positioning of future IIREVs users. Otherwise, figure 4 (b) shows a fairly gender-balanced panel. The quantitative survey results allow to conclude that the global trend is favorable to the IIREVs project but with some hesitations to be lifted. It can be noted that 84% of users are in favor of the principle of discharge-recharge of their EV (figure 5 (a)) and 97% do not mind that their EV is recharged by PV (figure 5 (b)).

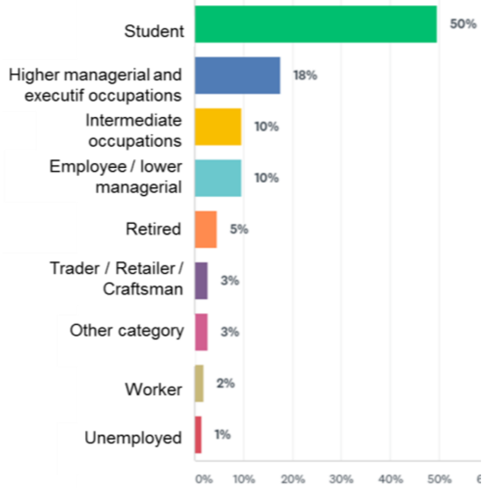

Figure 3. Socio-economic classification.

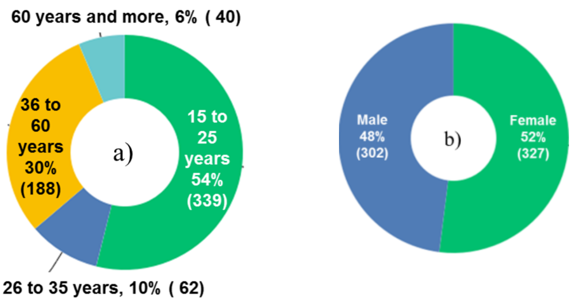

Figure 4. Age ranges for survey (a); Gender representation (b).

In addition, 96% of respondents are not opposed to the installation of the city car parking shades as a support to place PV sources. Both innovations, EV discharge and PV use, therefore seem to be accepted by many current and future users.

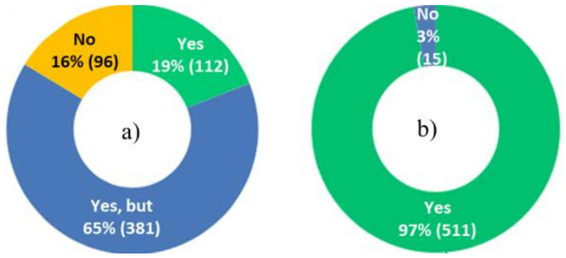

Figure 5. General trend to the discharge acceptability (a); General trend to the recharge of EVs by PV panels (b).

However, 64% of the respondents accept the discharge-recharge but under certain conditions. One of the conditions for respondents is to ensure financial balance. The majority does not desire to incur additional costs when using such an infrastructure, and some even see it as a financial incentive to gain some profit in sharing their energy. The compensation that comes out the most is an indirect compensation such as a deduction on their electricity bill and/or free parking. A second condition is that a majority of respondents prefer to give up energy for home use or public use, but would be less inclined to share their energy for the private use of a business. In addition, according to respondents, it is the local authorities that should have the largest role to play in the IIREVs implantation and management. A last condition relates to the habits: users would like that the discharge impacts as little as possible their mobility. They would also prefer to have a safety margin on the autonomy of their EV. In addition, they give some importance to know the destination of the discharged energy from their battery. They also expect an access to information on the autonomy and recharge time of their battery. These conditions highlight the importance of defining a suitable business model, which seems to be one of the factors determining the development of IIREVs on a large scale.

4. Action plan for the IIREVs project

After the survey analyze, an action plan to improve acceptance of the IIREVS project may be proposed. According to user expectations, there are three main actions to carry out:

– to build an appropriate interface to control its battery;
– to be attentive to improved PV technologies;
– to design the car parking shades well integrated into the urban environment.

The suggested actions are interesting and could be the subject of a full-fledged study with the aim of adapting the IIREVs to real needs (e.g. by type of displacement, by type of activity...).

5. Conclusion

This paper has focused on social acceptability of an innovative energy system based on microgrid powered EVs charging stations. The survey results show that the IIREVs are accepted socially by a large majority while some imperatives must be considered in the urban cases implantations. According to users' expectations, an action plan was highlighted in order to best fitting IIREVs in urban areas.

Acknowledgement

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