COST
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IN SCIENCE & TECHNOLOGY

SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: **15127**
STSM title: **Platoon based vehicular networks towards smart grid resilience**
STSM start and end date: **23/06/2017 to 30/06/2017**
Grantee name: **Sabita Maharjan**

PURPOSE OF THE STSM:

The main objectives of Sabita's STSM at Halmstad University are as following:

- Give a talk on *Vehicle to grid (V2G) towards Efficiency and Resilience in a Smart Grid*,
- Discuss vehicle-platoon-to-grid scenario for resilient operation of the smart grid during emergencies, and develop optimal power flow solutions
- Discuss possible collaborations for project proposals to EU and national calls.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

1. Discussions about **possible collaborations for combined research** led to two clear directions: ***vehicular communication for platoons*** and ***vehicle-to-grid (V2G)***. Although in future, vehicles are likely to be electric/plug-in-hybrid electric vehicles (PHEVs) for which various aspects of vehicular communication should also be addressed and optimized in addition to V2G bidirectional power flow, as of now, we decided to consider the two directions as two separate problems, and to begin working on a joint paper on the role of PHEV platoons towards the resilience of a smart grid focusing on technological disruptions, which is described in the Section: "Main Results Obtained".

2. Sabita gave a talk about *Vehicle to Grid (V2G) towards Efficiency and Resilience in a Smart Grid.* During the presentation, Sabita talked about
   - demand response management for V2G and peer-to-peer V2V electricity trade
   - software defined psedodym management system for secure vehicular clouds

   The audience included researchers working on both communication and smart grid, and the talk was received well. Discussions after the talk mainly involved *how to design the price function capturing real dynamics of V2G*, and *how to determine the cost for the deficit/excess power under dynamic scenarios*

3. Possible Collaborations for national and EU funding opportunities
   Prof. Vinel and Asst. Prof. Maben Rabi (also from Halmstad Univesity) had been under constant dicussions with Per Andreas Langeland from transportøkonosmisk institute

(Transport Economic Institute), Norway[1], to submit a proposal under the SAFER initiative[2] from Chalmers University, Sweden, to **Vinnova, EU Horizon 2020**[3]. The tentative title for the proposal is ***Vehicle speed control on twisty roads***. The main idea for the proposal is to utilize combined data from both vehicles and the road conditions to dynamically analyze and evaluate the safety conditions/performance, and to communicate with approaching vehicles the optimal speed, and other necessary parameters based also on specific characteristics of the vehicles. We decided to join our hands together, where Sabita will be working on analyzing energy efficiency for both data analytics and V2X communication, and designing green solutions for both components.

Sabita introduced the **pilot-e call**[4] to the group. Due to our overlapping interests and also partly complementary expertise, we decided to work together for this proposal also. The main idea for this call is to utilize both 5G and device-to-device (D2D) communications for optimal safety, optimal energy consumption and eventually optimal driving experience for the vehicles. One of the main drives is to extend this idea for electric vehicles. As call demands close-to-the-market solutions, we focus on the solutions that can be tested and validated within a couple of years. Industrial partners from Sweden, who had worked with Prof. Vinel and Asst. Prof. Rabi have shown some interest in the project to provide the testing vehicles, and other facilities, for testing and validating our solutions. These collaborators include Uniti, Sweden[5] and NEVS, Sweden[6]. We are still in the process of finding a Norwegian industry partner. We are planning to talk to ASKO[7] soon.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

We began working on a joint paper with a tentative tile ***PHEV platoons towards Smart Grid Resilience***. Next, we present the details about the work.

Power blackouts can be caused by device failures, system faults including updates with bugs, misconfigurations or even cyber attacks. We consider a scenario where a certain part of the power grid infrastructure (corresponding to a community/region) is not working due to technology-related disruptions. Although, power supply is crucial for proper operation of all kinds of infrastructure, during power emergencies, it may be more important to support the operation of critical infrastructure possibly with minimum possible power configurations. For instance, in a hospital only the emergency sections and operation-theaters can be operated. Similarly, basic communication and the most fundamental banking services are important.

We propose the use of PHEV platoons for providing power to such critical infrastructure units during power emergencies, to form a stable microgrid that can sustain itself until the connection to the central power grid is restored. As the battery technology advances, the use of (PH)EVs for V2G electricity trade has received much attention, e.g., [1], [2]. There are two factors that make both our scenario and the concept novel. First, despite the increasing interest of the research community in V2G electricity trade, the use of PHEVs in the case of power emergencies is a largely unexplored topic. Second, the potential of vehicle platoons (PHEV platoons) in contributing towards the stable operation of a microgrid, and consequently other critical infrastructure during such emergencies, has not seen much work either. In fact, PHEV platoons

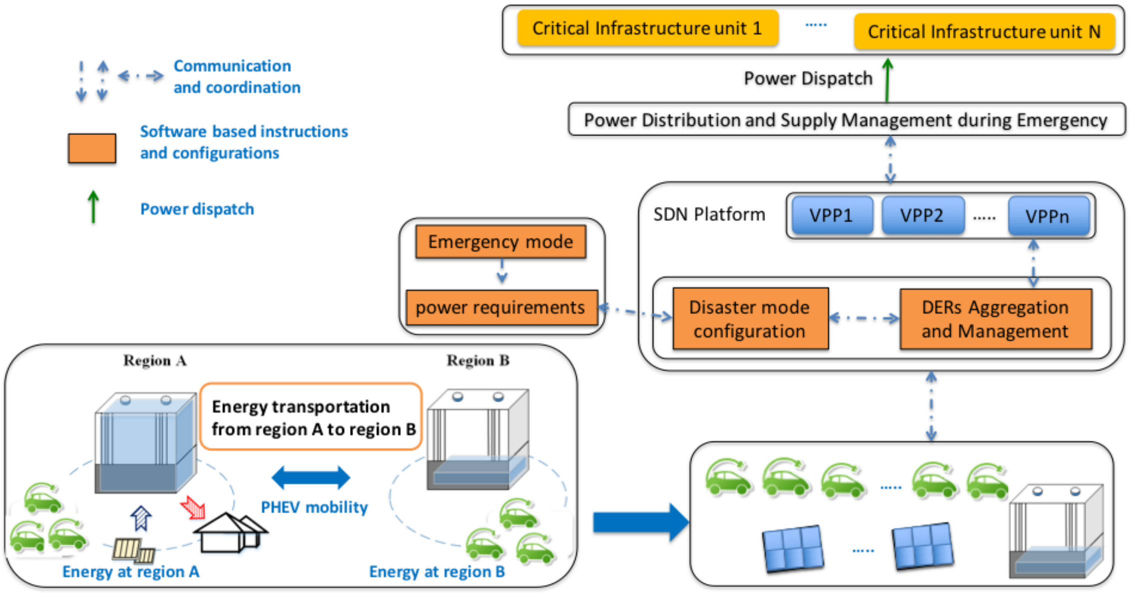
[1] https://www.toi.no/?lang=no_NO
[2] https://www.chalmers.se/safer.
[3] http://www2.vinnova.se/en/EU-and-international-co-operation/Horisont-2020/Horizon-2020-EU-framework-programme-for-research-and-innovation/.
[4] https://www.enova.no/pilot-e/utlysning-2---frist-11oktober
[5] http://www.unitisweden.com/.
[6] https://www.nevs.com/en/.
[7] https://www.asko.no.

possess a huge potential as the main supply to critical infrastructure or as extra supply for extended operation during power emergencies.(PH)EV platoons constitute a good example for the kind of group selling based V2G electricity trade scenario proposed in [1]. With a single or a few EVs, the amount of power they can supply may not be significant, while with PHEV platoons, the scale of the power supply will certainly be much higher, an advantage of particular interest especially for the power emergencies, although the motivation for introducing PHEV platoons in our model, may not be limited to economic incentives. The PHEVs can assume two different roles in this scenario.

- power supply to critical infrastructure units: PHEVs in and near the region can act either as the primary power supply to the critical infrastructure or as additional supply with renewable resources available with the critical infrastructure.
- mobile energy storage and transporters: The state of charge (SOC) of the PHEVs plays an important role in how much power they can contribute to the region. Nonetheless, making use of spatial diversity, PHEVs can also transport the renewable energy from neighbouring areas with excess generation [3][4].

While many critical infrastructure have alternate or backup solutions in the case of power outage, many may not have, and some may have local generators or UPS but these may prove insufficient during crisis for longer durations. E.g., uninterruptible power system (UPS) backups or local generators may be helpful to supply the necessary power to high priority areas of hospitals only for a short duration. A large free standing generator needs external fuel supply, frequent testing, and proper connections into the power grid. Alternatives like batteries and UPSs can be the solutions for limited amount of time, and if recharging is possible. The best option clearly depends on the amount of power necessary, the maximum duration that emergency power will be needed, and the cost of the backup option. In order to be prepared, the power requirements of the critical facilities and all other buildings in a disaster mode should be determined in advance. For this, the minimum configuration of all critical equipments including HVAC, security systems, etc. should be identified and put in a database. If there are any changes in the total power consumption due to additional new equipments or because of expanding the facilities and/or services, the minimum power requirement of the building in the disaster mode should be updated as well in the database.

For communication and proper coordination between diverse power resources (renewable generation in the microgrid, PHEVs, community storage units etc.) in order to make use of the available resources optimally, we propose a software defined networking (SDN) enabled framework for energy management. The framework is depicted in Fig. 1, where the lowest and the uppermost levels represent energy plain (energy sources, community storage units and PHEVs), and the middle level represents control plane (management) and data plane (communication of power-related data). We assume that basic communication services are in place i.e., the disruption is only in the power grid, and not in communication system. The base stations operate with their batteries for a certain duration. If the outage is extended, the PHEVs can also cover the BS power requirements.



Problem Formulation

In the disruption affected region, an SDN controller can communicate with local PHEV platoons and also bring in platoons from neighbouring regions to cover the power requirements of the critical infrastructure. Each critical infrastructure communicates with the SDN controller about its power needs, and the interested/called PHEVs and PHEV platoons also register themselves to the controller to directly supply or to transport and supply power to the critical infrastructure or to the community storage unit.

Let us denote a set of critical infrastructure units in the region as $CI \triangleq (CI_i | i \in \mathbb{M}), \mathbb{M} = \{0, 1, 2, ..., M\}$, where M is the total number of critical infrastructure units to be supplied power to. The discharging PHEVs in platoon n are denoted as $P \triangleq (PHEV_j^n | j \in \mathbb{J}_n, n \in \mathbb{N})$, where $\mathbb{J} = \{0, 1, 2, ..., J_n\}$, and $\mathbb{N} = \{0, 1, 2, ..., M\}$is the set of PHEV platoons, respectively. Let $d_i^{\min}$ be the minimum power necessary for $CI_i \in \mathbb{R}$ as specified in the *Power requirements* block shown in Fig. 1.

For the PHEV platoons, s_j^n is the amount of power that PHEV $j$of platoon n can supply to the region. We assume that the supplier PHEVs have charged their batteries from the same charging station (earlier), which means the cost function can be defined considering the total amount of power available from each platoon as energy unit. Making use of the widely accepted quadratic cost function for the supplied energy from the PHEV platoons, the cost function for platoon $n$can be defined as

$$C^n(\sum_{j=1}^{J_n} s_j^n) = \alpha \left(\sum_{j=1}^{J_n} s_j^n \right)^2 + \beta \left(\sum_{j=1}^{J_n} s_j^n \right), \forall n \in \mathcal{N}$$

, ...(1)

where $\alpha \geq 0$ and $\beta > 0$ are constants corresponding to the electricity price when the supplier PHEVs charged their batteires.

The optimization problem in this scenario is the cost minimization problem while ensuring at least the minimum power requirements of the critical infrastructure units. We define the problem as

$$\min_{\mathbb{S}:=\{s_i,\forall i\in\mathbb{M}\}} \sum_{n=1}^{N} C^n(\sum_{j=1}^{J_n} s_j^n) \quad \text{.....................(2)}$$

s.t.

$$\sum_{n=1}^{N}\sum_{j=1}^{J} s_j^n \geq \sum_{i=1}^{M} d_i^{\min} \quad \text{.....................(2a)}$$

$$s_i \geq d_i^{\min}, \forall i \in \mathbb{M} \quad \text{.....................(2b)}$$

$$s_j^n \leq \eta c_j^{n,\max}, \forall j \in \mathbb{Z} \quad \text{.....................(2c)}$$

where, $\mathbb{S}$ represents the supply vector to all the critical infrastructure units, with s_i as the supply to $\mathrm{CI_i}$, and s_j^n is the supply from PHEV j of platoon n, $\mathrm{c_j^{n,max}}$ is the battery capacity of PHEV j from platoon n, and $0 \leq \eta \leq 1$ indicates the minimum state of charge (SOC) threshold of the PHEV.

Current Status

As of now we are modelling the

- dynamics of renewable energy resources, and
- power consumption/requirements of critical infrastructure.

We will integrate these models with the optimization problem (2). After that, we will start working on implementing different components of the SDN framework shown in Fig. 1.

FUTURE COLLABORATIONS (if applicable)

Our dicussions during the STSM made it clear that both the groups share some common research interests. Nonetheless, our complementary expertise also opened the doors for us to collaborate for submitting EU and national level project proposals. We are therefore certain that we will be continuing our collaboration even beyond the outcome of this STSM. Our plan for future collaboration including the followup of the outcome of this STSM can be summarized as follows:

- After we finish modeling of the renewable energy resources and the power demand profiles of critical infrastructure, we are planning to submit the *PHEV platoons towards Smart Grid Resilience* paper to IEEE Transactions on Smart Grid.
- Vehicular communication for platoons during emergencies
  During the visit, we had a rigorous discussion also about the vehicle platoon communication aspect. We came up with two scenarios in the emegency context:
  - Modeling the reliability of vehicle platoon communication, and
  - Vehicle platoons acting as relays or network densifiers to facilitate communication services

  We will decide the venue for it later.
- We will submit at least one of the proposals discussed in the Section: "Description of the Work Carried Out during STSM", above.

References

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