Phase Unbalance Reduction through Coordinated EV Charging

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INTRODUCTION

- The increasing levels of EV penetration are expected to provide many challenges to grid companies.
- Charging EVs in the LV network could easily lead to unbalanced power flow, which will result in unbalanced voltage and current issues.
- In a three-phase grid network, current and voltage unbalance are intrinsically linked. However, voltage unbalance issues are usually more difficult to control than current issues.
- Current unbalance could increase the total losses incurred during power transmission and reduce the efficiency of electrical appliances.
- By properly adapting V2G technologies, EVs could be considered to provide ancillary services to mitigate these grid challenges.
- In this research we demonstrate a distributed consensus algorithm approach to regulating EV charging in order to mitigate current unbalance.

Objectives for the charging algorithm:

- **To be distributed**
- **To be easily implemented**
- **To be effective and efficient**

METHODOLOGY

- In a three-phase grid network (Fig.1), the condition for current balance is to equalise both magnitude and angle of the phase current i.
- By properly adjusting the EV charging rates, the in-phase and quadratic component on each phase of the current can be controlled. Fig. 2 illustrates the phase current decomposition.
- One sufficient condition to balance the current is to manipulate the in-phase (i_d term) and quadratic component (i_q term) on each phase current (Fig. 3) such that the active power flow is equalised and the reactive power flow is minimised on each phase.

$$\begin{bmatrix} i_{d1} \\ i_{d2} \\ i_{d3} \end{bmatrix} = \begin{bmatrix} \frac{P_{L1}+P_{EV1}}{V_{s1}} \\ \frac{P_{L2}+P_{EV2}}{V_{s2}} \\ \frac{P_{L3}+P_{EV3}}{V_{s3}} \end{bmatrix}, \begin{bmatrix} i_{q1} \\ i_{q2} \\ i_{q3} \end{bmatrix} = \begin{bmatrix} \frac{Q_{L1}+Q_{EV1}}{V_{s1}} \\ \frac{Q_{L2}+Q_{EV2}}{V_{s2}} \\ \frac{Q_{L3}+Q_{EV3}}{V_{s3}} \end{bmatrix}$$

Fig. 3 Current balance equation

- From Fig. 3, current unbalance is minimised when:

$$i_{d1} = i_{d2} = i_{d3} > 0$$
$$i_{q1} = i_{q2} = i_{q3} = 0$$

- In order to incorporate the design objectives of the basis consensus algorithm in a practical and scalable way, a hierarchical communication topology (Fig. 4) is proposed.

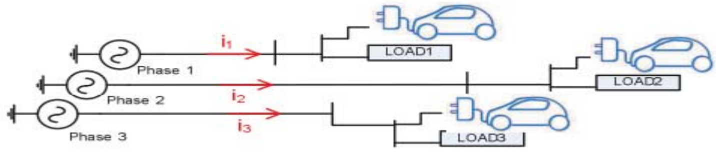

Fig. 1 A typical EV charging scenario in a three phase network

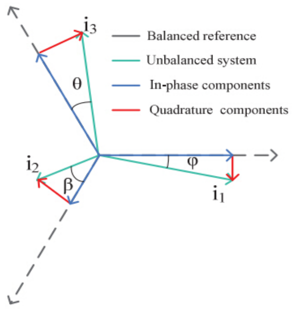

Fig. 2 Phase current decomposition

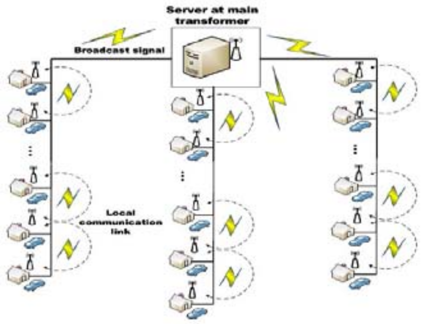

Fig. 4 Communication topology diagram

- With the proper communication infrastructure in place, the proposed algorithm is presented in Fig. 5 with function descriptions depicted in Fig. 6.

Algorithm 1 Distributed Consensus algorithm

while Battery not charged do
  for each $i \in \Theta_j(k)$ do
    $\delta_i(k) = \eta_a \sum_{h \in N_k^i} (C_i(k) - C_h(k)) + \mu_a . E_a^j(k)$
    $C_i(k+1) = \min(C_{max}^i, C_i(k) + \delta_i(k))$
  end for
end while

while Charger is active do
  for each $i \in \Theta_j(k)$ do
    $\lambda_i(k) = \eta_r \sum_{h \in N_k^i} (R_i(k) - R_h(k)) + \mu_r . E_r^j(k)$
    $R_i(k+1) = \min(R_{max}^i, R_i(k) + \lambda_i(k))$
  end for
end while

Fig. 5 Distributed Consensus algorithm

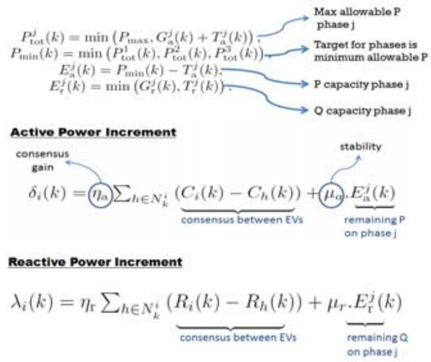

Fig. 6 Function descriptions of the algorithm

RESULTS

- The following diagrams demonstrate the performance of the algorithm with respect to active power consumption (Fig. 7) and the incurred neutral current (Fig. 8) on each phase of the grid in a 24 hour simulation.

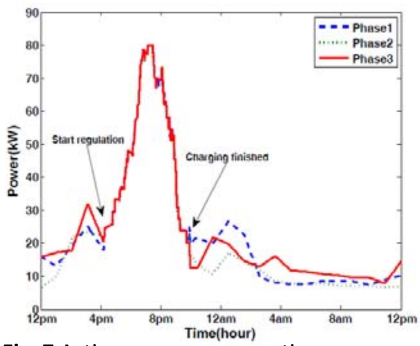

Fig. 7 Active power consumption

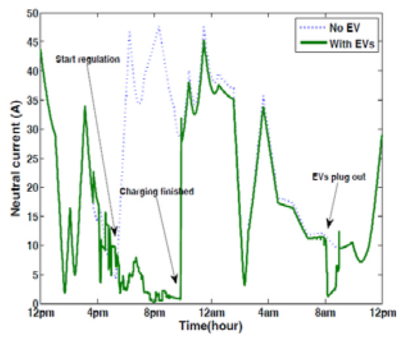

Fig. 8 Incurred neutral current magnitude

CONCLUSIONS

The proposed distributed consensus based EV charging algorithm offers a "plug and play" type of approach to employing EVs to mitigate current unbalance issues on the power grid.

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