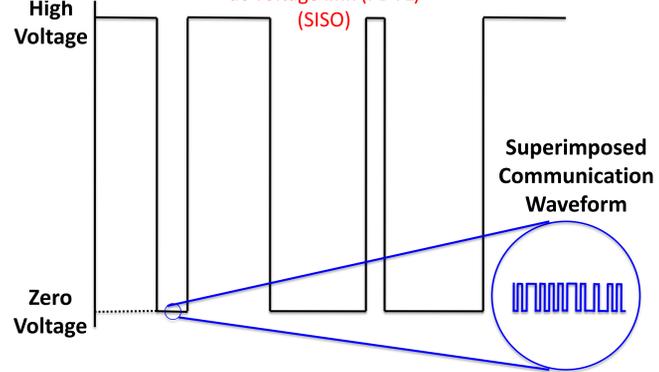


Boolean Microgrid¹

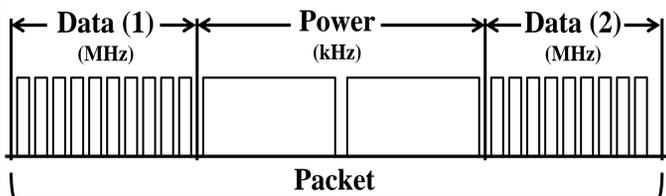
Boolean microgrid is a radically new CPS that enables dynamic “need based” spatio-temporal “discretized” (and if needed “codified”) power and data delivery over waveguide as well as free space. It can simplify system complexity, mitigate distributed energy storage needs, and yield enhanced efficiency and reliability.



Fast power transfer over a pulsating-dc voltage link (PDVL) (SISO)



¹S.K. Mazumder, “Boolean microgrid”, patent pending, 2013.



Research Issues:

- As the frequency of power transmission is increased, transmission-line (TL) length at which the TL effects onset decreases. This leads to an escalation in power transmission losses and loss of signal integrity. **So, a key question is what will be the outcome of TL effects on a Boolean Microgrid and how can one mitigate them?**
- To realize need based power flow a bi-directional communication architecture is required for the information exchange between distributed loads and sources. **Can this be achieved using the available network architectures or a custom network architecture has to be designed?**
- Due to the delay introduced by the TL effects, information exchange between the distributed loads and sources gets affected. **So, an important issue is what will be the effect of delayed communication on the performance of power converters and how can these effects be minimized?**

The results presented in this poster, indicate that the choice of power transmission frequency plays a pivotal role in mitigation of TL effects (which in turn reduces transmission loss and ensures signal integrity). A new communication architecture is proposed. An estimator based control algorithm has been designed for control of power converters to counter the effects of delays caused by TL(s).

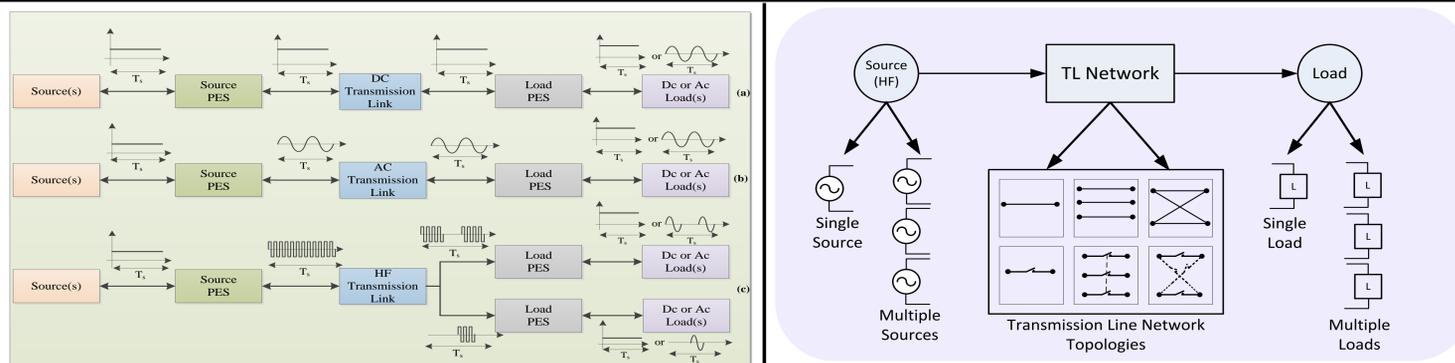
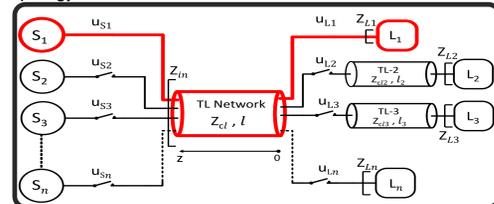


Fig. 1. Architecture of (a) dc, (b) ac, (c) need-based asynchronous HFDPs network and Generalized High Frequency Distributed Power System (HFDPs)

Frequency Dependent Criterion for Mitigation of Transmission-Line Effects in HFDPs

A generalized frequency dependent criterion for mitigating TL effects has been developed in [2] for n mutually coupled TL. Below is an illustration of this criterion for a SISO with HFDPs topology.



In a SISO topology shown above, Input impedance (Z_{in}) is given by

$$Z_{in} = Z_{cl} \frac{(Z_{L1} + jZ_{cl} \tan \sqrt{\beta_1} l)}{(Z_{cl} + jZ_{L1} \tan \sqrt{\beta_1} l)}$$

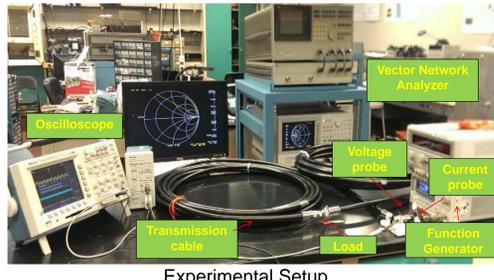
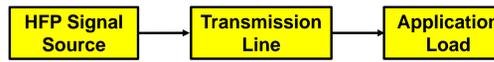
Substitution of $\beta_1 l = n\pi$ (where n is an integer) yields,

$$Z_{in} = Z_{L1}$$

The set of frequencies at which this is satisfied ensures maximum signal integrity as well as power quality and is given by:

$$f = \frac{nv}{2l}$$

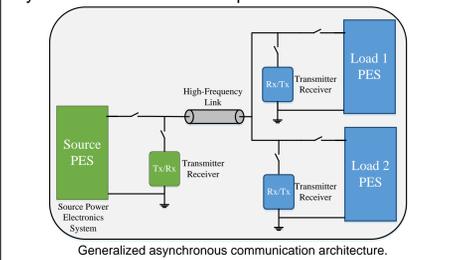
v represents velocity of wave propagation



Experimental Setup

Bi-directional Communication Architecture for Distributed Power Converters

Since all the available power line communication (PLC) architectures are designed for low-frequency power signals, a novel communication architecture is being developed to realize high-frequency asynchronous and discrete power and data flow.



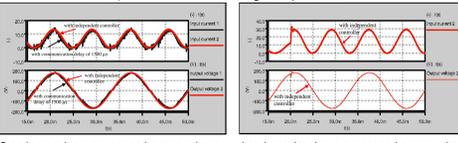
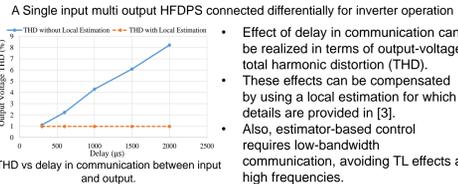
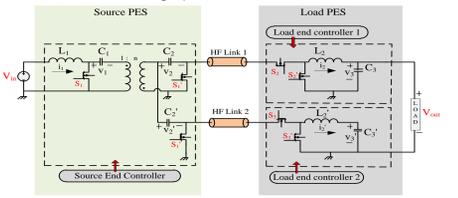
- Advantages:**
- Asynchronous/need-based power and data delivery can be realized.
 - Asynchronous communication can ensure maximum utilization of the available network bandwidth.

- Challenges:**
- Available protocols are too complex for cost effectiveness and efficient power conversion hence a custom protocol is to be designed.
 - Fast data recovery and synchronization circuits are required at the receiver end.

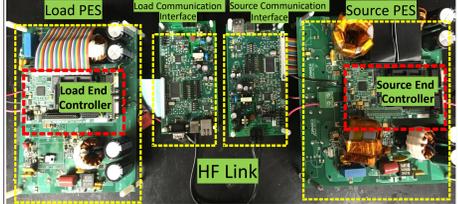
- Publications:**
- A. Gupta, N. Kumar, S.K. Mazumder, “Frequency-dependent criterion for mitigation of transmission-line effects in a high-frequency distributed power systems”, IEEE Energy Conversion Congress and Exposition, pp. 4624-4631, 2015
 - A. Gupta, N. Kumar and S.K. Mazumder, “High Frequency Power Distribution System in Presence of Transmission-Line Effects”, in review, IEEE Trans. on Power Electronics, 2016.
 - N. Kumar, A. Gupta, D. Chatterjee and S.K. Mazumder, “Estimator Based Independent Control Architecture for a Need-Based Asynchronous High Frequency Distributed Power System.” Selected for publication in APEC 2017.

Estimator Based Control for Delay Compensation in HFDPs

A distributed power electronics converter connected in a SIMO configuration was designed and fundamental switching sequence was so chosen that it emulates single phase Cuk inverter.

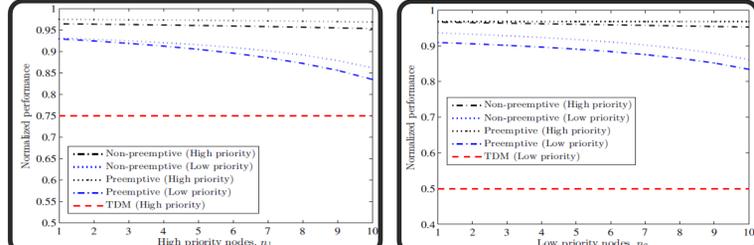


Steady-state input-current and output-voltage waveforms with the independent controllers and delay in communication supported with (red) and without (black) local estimation.



Experimental prototype for a need-based asynchronous HFDPs supporting an inverter (DMI) configuration

Need based Control Data Transfer in Boolean Microgrid



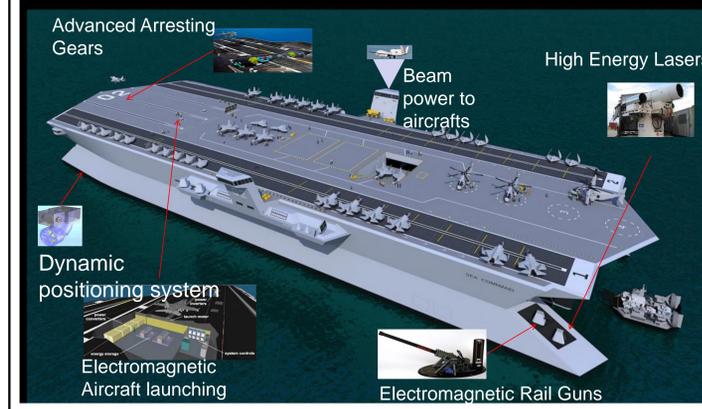
Research Issue: Since the transfer of power is need (e.g., demand) based and generation of these needs may/are not always be periodic, what will be the impact of control based asynchronous data transfer as opposed to conventional TDMA based approaches?

The initial results (as demonstrated in the figures to the left) clearly indicate that there may be a significant improvement in performance with regard to throughput utilization and delay mitigation. Details are provided in M. Tahir and S.K. Mazumder, Dynamic priority based event-driven communication in smart grid, in review, IEEE Transactions on Smart Grid, 2014.

Should Power be Distributed only at 60-Hz AC or at DC and continuously?



How about for massive computer power servers where high frequency (instead of conventional ac/dc) power distribution can significantly reduce system complexity and reduce energy-storage requirements?



How about for next-generation electric warfare ships where the most challenging loads are intermittent and impulsive and distributed energy storage not an inexpensive proposition?



How about rapid charging of an array of vehicles wirelessly where DC is out question and 60-Hz AC yields huge system size?

And, there are many more such distributed mini/micro grid applications (e.g., for space, electric vehicles, aerospace, telecommunication, robotics, smart buildings, induction heating), where “just in time” power transfer guided by col-located smart communication-control can make significant reductions in system complexity, power loss, energy storage and bandwidth-need. **But, what would that energy cyber-physical system (CPS) mechanism be?**