Nanogrid: DC Based Energy Distribution and Control

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Experience
1. **2000-2004:** Research Assistant at University of Florida
2. **2004-2008:** Staff Application Engineer at International Rectifier Corporation, North Kingstown, Rhode Island
3. **2008-2012:** Assistant Professor at IIT Kanpur
4. **2012-Present:** Associate Professor at IIT Kanpur

General Research Interest
1. DC/DC power conversion
2. Power Electronics Converters & Control
3. DC Based Power Distribution
4. Renewable Power Supplies
5. Nano-grids
What the talk is all about?

1. What are Nano-grids

2. How are they related to a Smart-grid (SG)

3. Role of Multi-port Converters in a Nano-grid

4. Some Prospective on creating a sound SG
Sequence

1. Smart-grid: Introduction
2. Nano-grid: As a part of Smart-grid
3. Nano-grid: Research Problems and Solutions
5. Different Strokes!!
6. Research Asset
Conventional Grid Vs Smart Grid

- Power Station
- Transmission Grid
- Substation
- Distribution Transformer
- Homes
Smart Grid?

What?
The application of intelligent, co-operating resources to create a flexible electric power system is referred to as smart grid.

- Two-way flow of power and info in distribution grid
- Information technology is used to improve grid function
- Interconnection of high number of automation devices

Why?

- Increases penetration of renewable energy sources
- Enables active participation of consumers
- Improved Reliability
- Optimizes power quality (Reduces Brownouts!!)
Conventional Grid Vs Smart Grid

- Power Station
- Sub Station
- Distribution System (Single Phase)
- Domestic Wind-Turbines
- V2G and G2V
- Distributed Energy Resources (DER)
- Solar Powered Homes
Smart Grid: Characterization

Smart Grid

Smart Infrastructure

Smart Energy System

Power Generation

New Paradigm (V2G, G2V, Microgrid, etc.)

Smart Management

Smart Info System

Distribution Grid

Smart Protection

Smart Comm. System

Transmission Grid
Micro-grid Integration

VPS ~ 50 kW

- Each Micro-grid should work autonomously.
- Each Nano-grid should work autonomously.
- Leads to reliability and fault tolerant Smart-grid
Observations

1. Microgrid are building blocks of a Smart-grid.
2. Nanogrids are building cells of a Micro-grid.
3. They should be efficient, reliable, self-sufficient, and fault tolerant to contribute to a healthy smart grid.

Strategies

1. A Nanogrid may not be directly connected to a grid.
2. It should stably operate in clusters (in a Microgrid).
3. It should be able to operated in an islanded mode.
4. Nanogrid should be Operationally independent to make the Smart-grid reliable and fault tolerant.
5. **Reduce the number of converters in Nanogrid.**
Nanogrid
Research Problems &
Proposed Solutions
Basic Architecture: Why DC?

Arg. 1: Generates Power at DC

Arg. 2: Modern Loads are DC Compatible

Inside Home (small geographic area)
Arg. 2: Modern Domestic Loads (Lightings)

Modern Domestic Loads (Lightings)

Rectifier
Inverter

230 VAC/50 Hz
110 VAC/60 Hz
160 VAC /45 kHz

Rectifier → Inverter

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Arg. 2: Modern Loads: DC Compatibility
Nanogrid: Present Technology

1. Dedicated converter for each job: Can it be Improved
2. All converters communicate with Energy Control Center (ECC)
3. Power electronics intensive with no need of protective gears
Energy Control Center (ECC)

Role of Communication

Sub Station

Less Converters Less communication => Reliable System

Virtual Source

Micro-grid

Nanogrid

Micro-grid

Nanogrid

Nanogrid

Nanogrid
How to Improve this Technology?

1. Efficient Design Strategies
   a. Transformer-less Single topology for Multiple jobs
   b. Single-input Multi-output converters
   c. Multi-input Single-output converters

2. Battery life: Improved battery charging strategy
   a. Smart charging circuits

Reduces the no. of converter stages to improve reliability
How to Improve this Technology?

1. Efficient Design Strategies
   a. Transformer-less Single topology for Multiple jobs
   b. Single-input Multi-output converters
   c. Multi-input Single-output converters

2. Battery life: *Improved battery charging strategy*
   a. Optimal charging circuits
Versatile Renewable Power Module (VRPM)
Motivated by Needs of Rural India: (Developed for GE Global Research)

- A transformer-less High step up Inverter
- Bidirectional power flow
- Same topology for any kind of renewable power conversion

Olive Ray, Santanu Mishra, and Avinash Joshi, ECCE 2012
**Versatility** – Ability to interact with different Input-Output types.

**Modularity** – Same Topology to be used for all Operations.

**Scalability** – Ability to cater to higher demand.

**Efficient/Volume** - Intended for smaller systems in rural areas
How to Improve this Technology?

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   c. Multi-input Single-output converters

2. Battery life: *Improved battery charging strategy*
   a. Optimal charging circuits
Single-Input Multi-Output Converters
Switched Boost Inverter (AC-DC outputs)

- Simultaneous AC and DC loads
- The converter has excellent cross-regulation.
- Converter has excellent EMI immunity

Ravindranath Adda, Santanu Mishra, and Avinash Joshi, IEEE Trans. On PE, ECCE 12, EPE 12
Boost Converter (AC-DC outputs)

Hybrid Boost is obtained by simple modification of a Boost: Produces DC and AC outputs

Olive Ray and Santanu Mishra, ECCE 12
Typical Application: Hybrid Class Converters

Conventional DC Nano-grid

DC Nano-grid with SBI

Ravindranath Adda, Santanu Mishra, and Avinash Joshi, IEEE Trans. On PE
Special Converters For Nanogrid

Conventional Converters shorts in HF-application due to Shoot-through

• These new inverters allow shoot-through: Better EMI
• Suitable for compact high frequency applications
Flavour of Research: Special PWM Control

Ravindranath Adda, Santanu Mishra, and Avinash Joshi, IEEE Trans. On IE
Flavour of Research: Control and Performance

Cross-regulation

Non-Linear Load

Ravindranath Adda, Santanu Mishra, and Avinash Joshi, IEEE Trans. On PE

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Single-Input Multi-Output

- $V_{o1}$ is always higher than $V_{in}$
- $V_{o2}$ may be higher or lower than $V_{in}$

Olive Ray, Anil J., and Santanu Mishra, ISIE 13
How to Improve this Technology?

1. Efficient Design Strategies
   a. Transformer-less Single topology for Multiple jobs
   b. Single-input Multi-output converters
   c. Multi-input Single-output converters

2. Battery life: *Improved battery charging strategy*
   a. Optimal charging circuits
Multi-Control Single-Input

Converter

48 V-96 V-144 V

Multi Input Battery Charger

12 V

24 V

Multiple Solar Panel Inputs

Converter needs to be versatile to adapt to various needs

P-V Curve

Operating Point (MPP)
1. Efficient Design Strategies
   a. Transformer-less Single topology for Multiple jobs
   b. Single-input Multi-output converters
   c. Multi-input Single-output converters

2. Battery life: *Improved battery charging strategy*
   a. Optimal charging circuits
Battery Charging Basics

Ideal Charging

Actual Charging

Reason for irregularities in actual charging
Optimal Battery Charging

Bi-Directional Coupled Inductor Converter

K \( i_L + \) offset

DD

CEA

PWM + TIMER LOGIC

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What’s Next ???
(Research Directions)
Building a Nano-grid

Energy Control Center
(Hybrid Converter)

DC Distribution Bus -- $V_{Bat}$

Load Center 1
(Multi-Port DC)

Load Center 1
(Multi-Port DC)

μ-Grid

Boroyovic ‘10

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1. Micro-grid are interconnected using a 50/60 Hz
2. Interconnection is three phase through a Δ-Y transformer
3. Fully controlled Autonomous operation using local measurements only
4. Static Switch activates in case of abnormality (IEEE 1547, Faults, etc.)
Interconnecting Nanogrids

Why do we have 50/60 Hz AC?

- Electromechanical Machines yield better to this frequency
- Less inductive drop when geographic area is high
- Rest of the World: 50 or 60 Hz depends on where the countries bought their equipment from (US or Europe)

Present Scenario: We are not handicapped by these factors anymore as

(a) Geographic area is smaller (Low inductance)
(b) No Electromechanical conversion to limit frequency
(c) Higher frequency operation will lead to smaller transformer
Options 1: Interconnecting Nanogrids (HFAC)

1. Nanogrid can generate high frequency AC (HFAC, 1 phase)
2. Isolation transformer size is reduced if HFAC used
3. Harmonic order is higher leading to smaller filters
4. Static switch is easier to design as current has a zero crossing
5. Nanogrids operate in a peer-to-peer (no master) fashion
6. All Nanogrids are controlled based on their local measurements only
HFAC Sources

A Wide Power Bandwidth
Differential Boost Inverter

- Conventionally VSI based Inverters are used.
- This research uses a Boost based inverter
- Excellent Power bandwidth and dynamic response
Options 2: Interconnecting Nanogrids (DC)

Microgrid Distribution (DC)

1. Nanogrid can generate HV-DC (at 1 kV or so) for distribution
2. Individual overall isolation not possible
3. Static Switches have to be over-rated as no zero crossing in current.
   (DC switch gears: Hard to quench the arc)
4. No reactive component
5. Nanogrids operate in a peer-to-peer (no master) fashion
6. All Nanogrids are controlled based on their local measurements only
Conclusions of Nano-grid Research

1. DC based distribution is more suitable for Nano-grids
2. Various multi-port converter topologies are proposed
3. Multi-port converters make nano-grid reliable

Research Topics to be addressed

1. Nano-grid Interconnection using HFAC or HVDC
2. Power balance studies of the system of Nanogrids
3. Fault studies of the system of Nanogrids
4. Communication between Micro and Macro systems
Different Strokes !!
Rural Telecom Problem

**Objective:**
How to sustain the smile without digging deep into the company’s pocket??

**What on the way?**
- Exchanges in Remote places
- Grid is intermittent and unreliable
- Available in 1-2-3 phases in different time of the day
- Power plants only work with 3 phase supply grid or diesel generators

**Solution:**
A power plant that works seamlessly with 1-2-3 phases without any derating
A Novel Rectifier Concept!!

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Commercial Production

DCPS-048-3/1H is designed based on High Frequency Switching Mode Techniques providing continuous power supply for high capacity and mission critical equipment with a reliable power protection. This system uses switching frequencies of 20kHz and above making it highly efficient, light weight, compact, and easily transportable. In this system, three phase input supply is given to a single module, thus eliminating the requirement of additional modules as in the case of earlier systems. The system delivers the rated output of 48V, 50A even if two out of the three phases are available and delivers half the rated output i.e 48V, 25A even if a single phase is available, thus ensuring continuous output. The system automatically adopts itself to the changes in the input supply. This system is compatible with both VRLA as well as Conventional Lead Acid batteries.

Built using robust design, this product is fully modular and as such is both customizable and scalable to meet a variety of applications, mainly in the rapidly expanding Telecom network in Rural and Remote Areas. It has also been designed to be hot-swappable, which means down time is not just reduced; more importantly, repair and maintenance can be done without having to take the entire unit offline.

This system essentially consist of 3 sections:
- Power Modules [PM]
- Control Supervisory Unit [CSU]
- Enclosure Cabinet

**Special Features:**
- Output of 48V, 50A with 3-ph or 2-ph Input Supply and 48V, 25A with 1-ph Input Supply
- Scalable DC Power system
- Hot-Swappable power modules
- Automatic Switching between 3-ph and 1-ph
- Modular, Compact and Portable
- Expandable module rack

**Applications:**
- Telecommunication systems in both Rural as well as Remote Areas
- In applications where constant and continuous power supply is required
Miscellaneous Research: Eload

Steady State

Transient Response

Saurabh Upadhyay, Santanu Mishra, and Avinash Joshi, IEEE Trans. On IE, APEC 11
Research Asset
Research Facilities

**Simulation:**

*Mathematical Computation Tools:*
Matlab, Simulink Modules, Mathcad Pro. Licenses

*Real time Simulation Tools:*
PSpice professional licenses

**Prototyping:**

*PCB Layout Software:*
Orcad Allegro Pro., Altium DXP

*Soldering:*
95 W contact soldering tools and 300 W non-contact surface mount rework station.

**Experimentation:**

Range of power supplies, high-end scopes (isolated and non-isolated types), High-end and regular Multi-meters, Thermal Measurement tools, Function generators, Altera FPGAs boards and Interfaces, DSP kits

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Group (Started in 2008)

Funding: Above $200,000
- DST (Equivalent of NSF in India)
- BSNL (Telecom)
- General Electric Global Research

Research Publications:
- Transactions: 12
- Conferences: 29

Group:
- Ph.Ds=3 (On-going) +1 (About the Submit)+ 1 (Graduated)
- M. Tech=4 (On-going) + 15 (Graduated)

To learn More:
- Please visit @ www.iitk.ac.in/~santanum
Questions !!