Smart Transformer for Realizing Meshed and Hybrid Electric Distribution Grid

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IIT Guwahati, India

Established in 1995

North-eastern part of India

Total faculty: 430

Total students: 7500

QS world university ranking: 384

Electronics and Electrical Engg. Department

Established: 1995

Total faculty: 50

Total students: Approx. 1000

Electric Power faculty: 8

Brief Introduction

Chandan Kumar, Associate Professor at IIT Guwahati, EEE Department
PhD: IIT Madras, India, 2014
Postdoc: University of Kiel, Germany (2014-15)
Alexander von Humboldt fellow: University of Kiel, Germany (2016-17)

Major Research Area

Smart transformer, renewable energy integration, meshed and hybrid microgrid, power quality

Outline

- Challenges in Modern Power Distribution System
- Various Solutions
- Introduction to the Smart Transformer
- Some Applications of Smart Transformer
- Challenges in Smart Transformer Applications

Grid Transformation

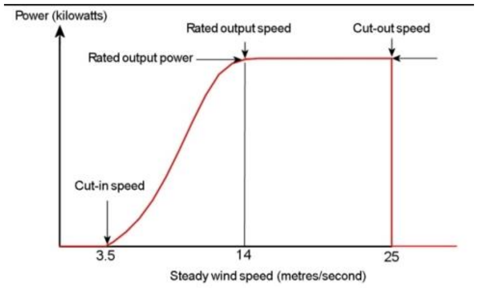
High dependency on depletable resources

Attempts to shift towards green energy

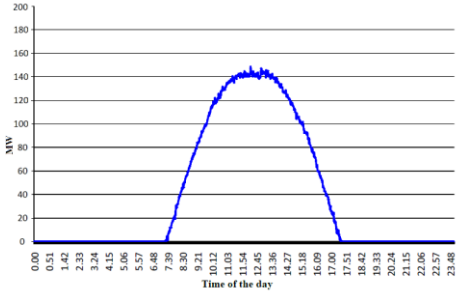
Increasing renewable energy penetration

Necessity for changes in grid and challenges

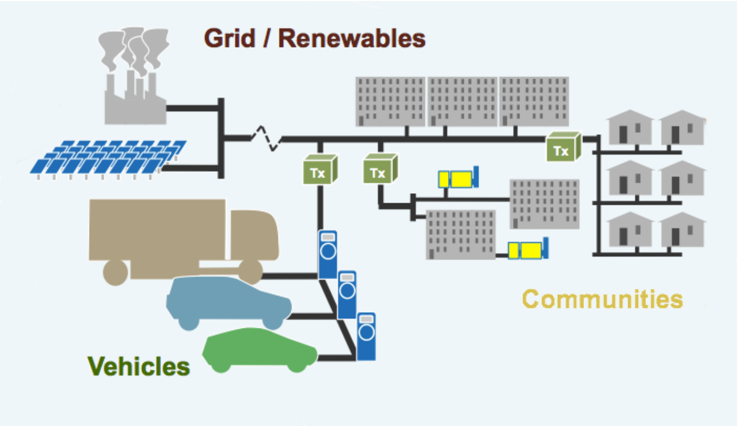
- Intermittent Power
- Both ac & dc power
- Voltage variations
- Faults
- Harmonics
- Microgrids
- Islanded operation
- Control complexity



Typical wind turbine power output with steady wind speed [2]



Solar bell curve [1]



Typical futuristic grid [3]

1. Gujarat Energy Transmission Corporation Limited. MNRE RE integration [Online]. Available: http://mnre.gov.in/file-manager/UserFiles/presentation-21102014/MNRE_RE_Integration_GETCO.pdf
2. Wind Power Program. Wind turbine power output variation with steady wind speed [Online]. Available: http://www.wind-power-program.com/turbine_characteristics.htm
3. M. Kisacikoglu, T. Markel, A. Meintz, J. Zhang and M. Jun, “EV-grid integration (EVGI) control and system implementation research overview” National Renewable Energy Laboratory (NREL), Long Beach, CA, Res. Overview NREL/PR-5400-65861, Mar. 2016.

Impact of DG penetration

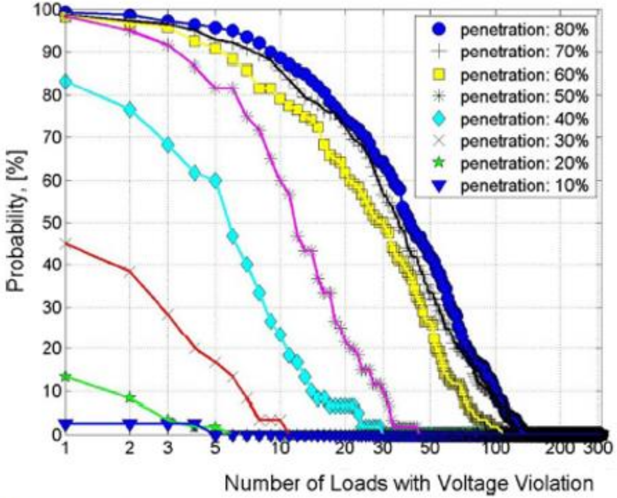
Grid designed as passive

⇩

Massive integration of DG in the distribution grid

⇩

If the DG penetration increases over certain value, the voltage violations occur in the whole grid



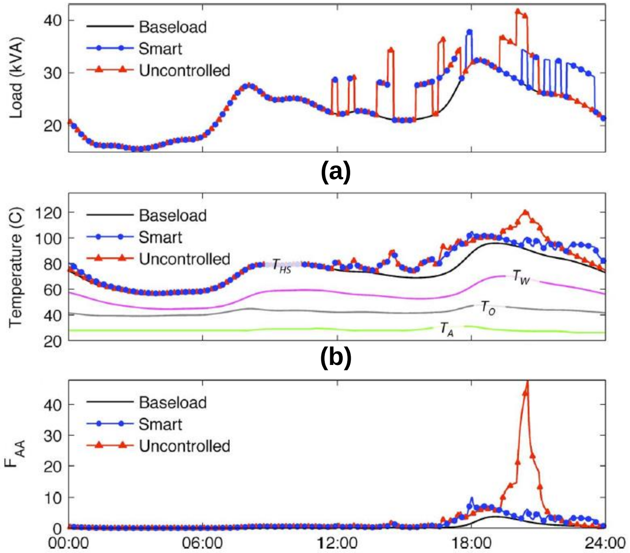
Probability of having voltage violations of more than ±5% versus the number of loads with violation.

Po-Chen Chen; Salcedo, R.; Qingcheng Zhu; de Leon, F.; Czarkowski, D.; Zhong-Ping Jiang; Spitsa, V.; Zabar, Z.; Uosef, R.E., "Analysis of Voltage Profile Problems Due to the Penetration of Distributed Generation in Low-Voltage Secondary Distribution Networks," *IEEE Transactions on Power Delivery*, vol.27, no.4, pp.2020-2028, Oct. 2012

Impact of EV penetration

The massive penetration of electric vehicles may lead to:

- Voltage deviation* from the rated value
- More power Losses*
- Transformer aging** due to the increased current demand



(a)

(b)

(c)

EVs impacts on the transformer*: (a) Power Profile, (b) Transformer Temperature, (c) Aging Factor

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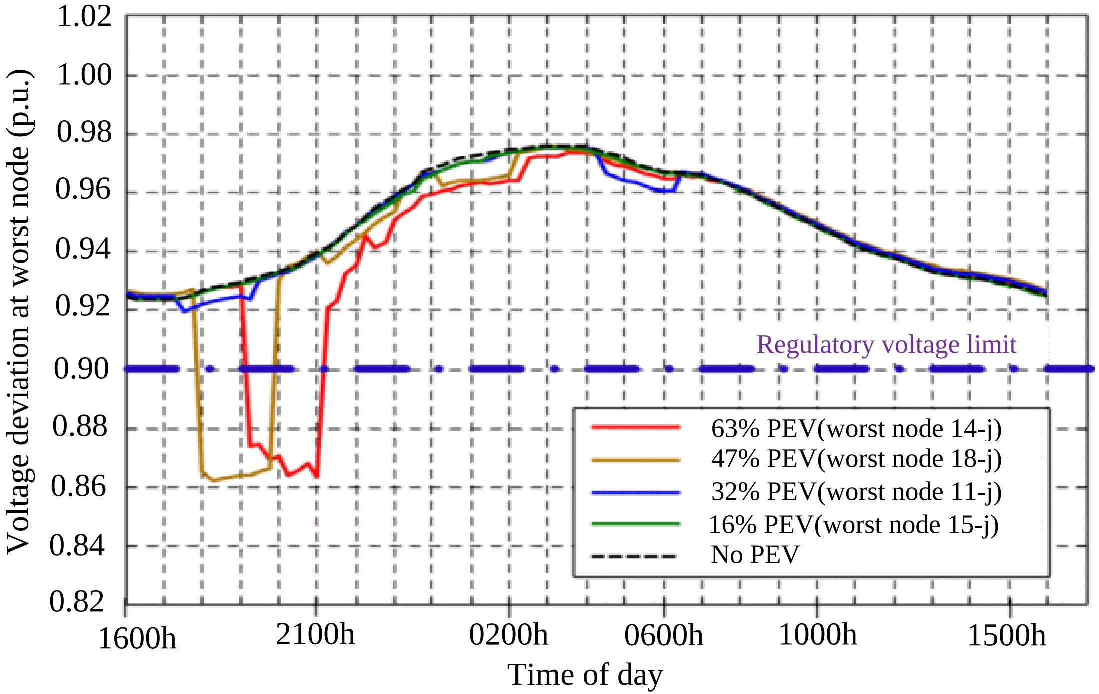
*Clement-Nyns, K.; Haesen, E.; Driesen, J., "The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid," *IEEE Transactions on Power Systems,* vol.25, no.1, pp.371-380, Feb. 2010

**Hilshey, A.D.; Hines, P.D.H.; Rezaei, P.; Dowds, J.R., "Estimating the Impact of Electric Vehicle Smart Charging on Distribution Transformer Aging," *IEEE Transactions on Smart Grid*, vol.4, no.2, pp.905-913, June 2013

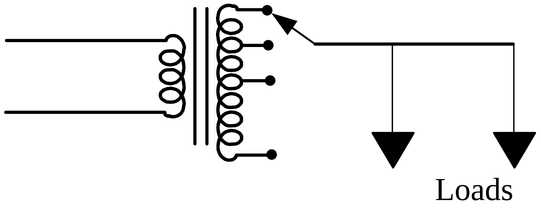
Impact of EV penetration



- Voltage limits are violated due to the uncontrolled EV charging

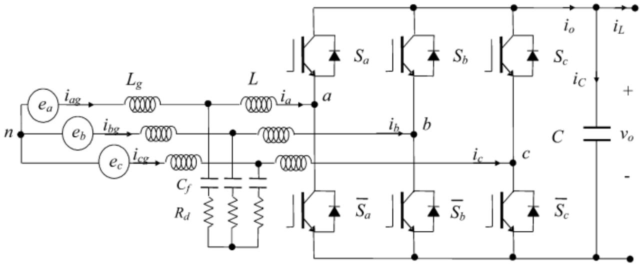
S. Deilami, A. S. Masoum, P. S. Moses, and M. A. S. Masoum, “Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile,” IEEE Transactions on Smart Grid, vol. 2, no. 3, pp. 456–467, Sep. 2011.

Existing Solutions



On-load tap changer

Voltage control

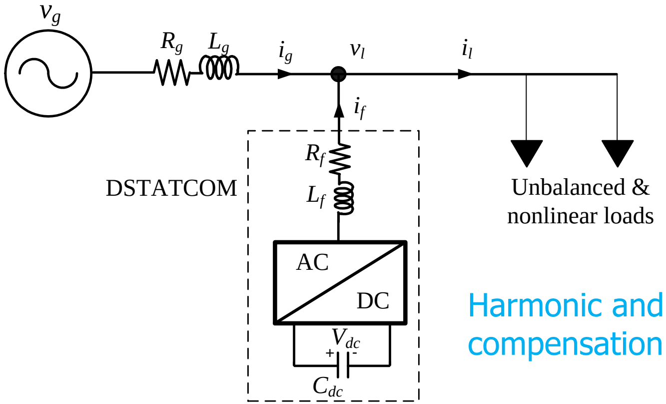


Active rectifier

DC-link control, power factor control

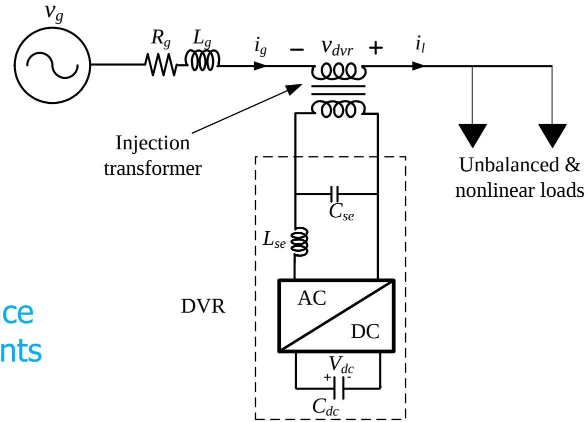
- Multiple solutions are proposed to tackle these challenges
- More enhanced control structures integrated with DGs are proposed to control active and reactive powers

Solutions Available in Literature



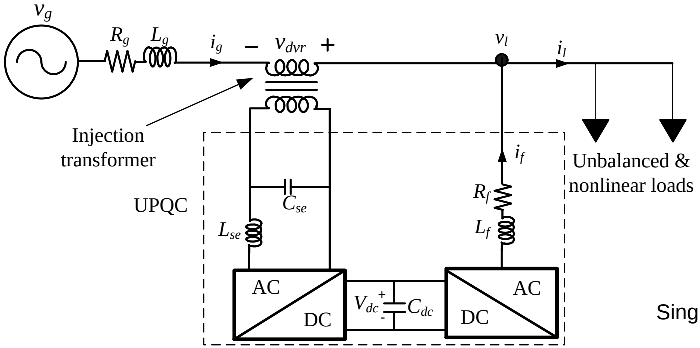
Single-line diagram of D-STATCOM

Harmonic and unbalance compensation of currents



Single-line diagram of DVR

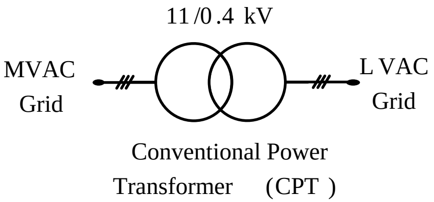
Voltage sag/swell mitigation

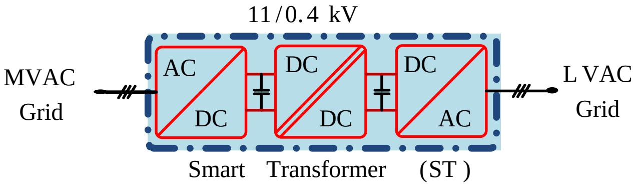


Simultaneous voltage and current compensation

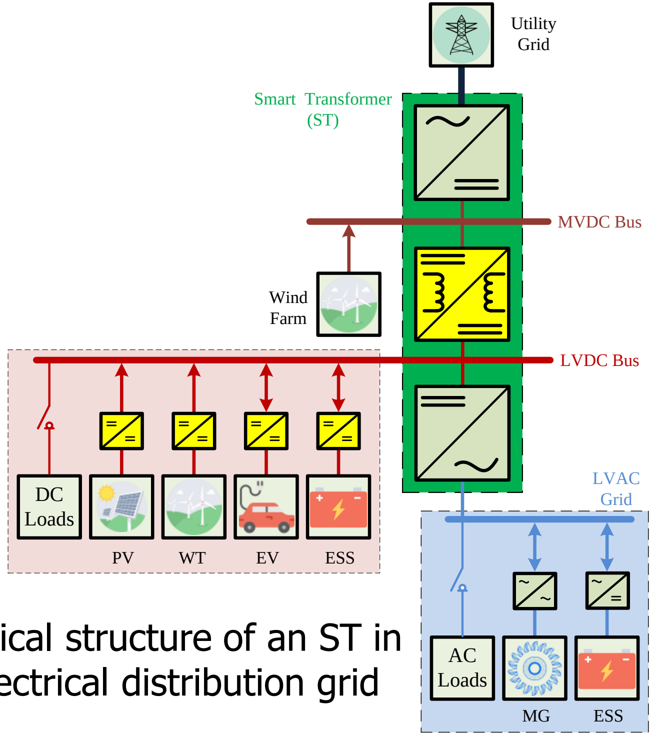
Single-line diagram of UPQC

The Smart Transformer



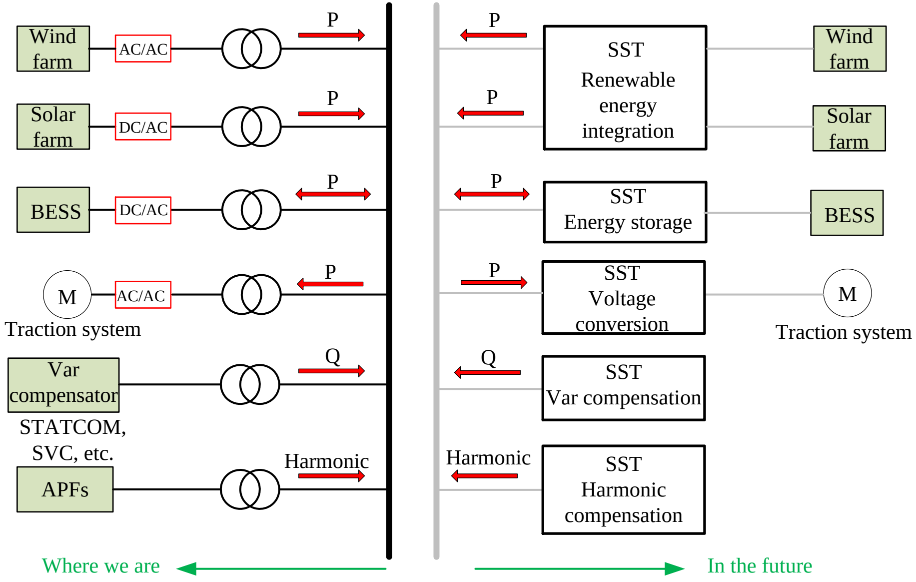


- A power electronic transformer with added control functionalities
- An alternative of conventional power transformer
- A support to connect storage, renewables, and EV infrastructure at LV and MV DC links



Typical structure of an ST in electrical distribution grid

Potential Applications



X. She, A. Q. Huang, and R. Burgos, “Review of solid-state transformer technologies and their application in power distribution systems,” IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 1, no. 3, pp. 186–198, Sep. 2013.

Basic Operation of ST: Balancing Voltage and Current

Grid components:

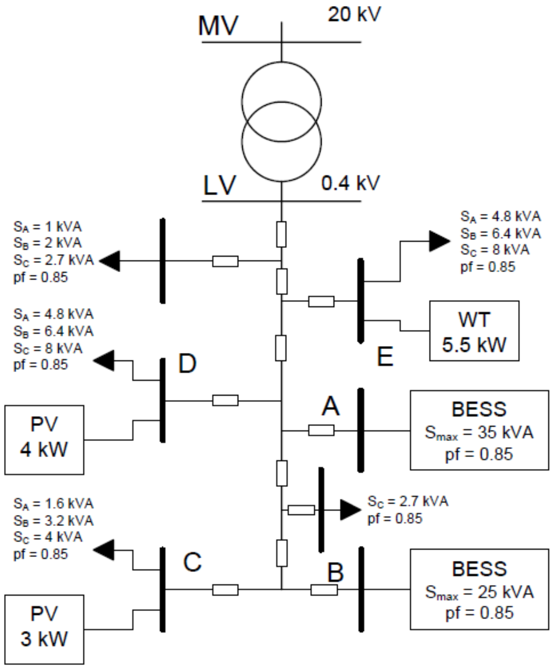
- Transformer ratio: 20/0.4 kV
- Unbalanced Load (pf: 0.85 p.u.)
- Fixed Speed Wind Turbines 5.5 kW
- 2 BESSs of 35 kVA and 25 kVA, with voltage droop controller implemented
- 2 PV plant of 3 kW and 4 kW

Presence of unbalanced loads and single-phase connected DG:

x Unbalanced voltages in LV grid

x Unbalanced current demand in MV grid

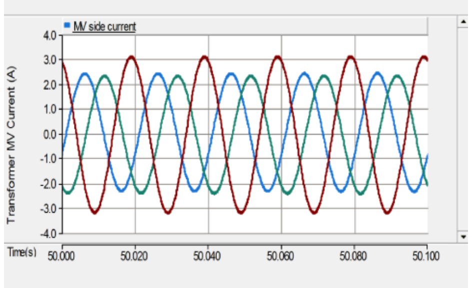
LV Cigré 12-bus feeder grid



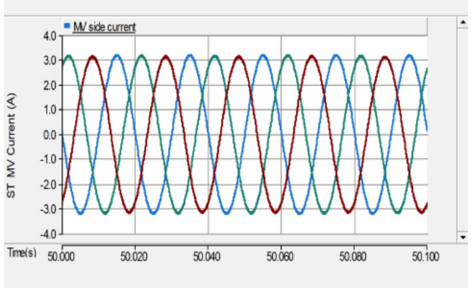
G. De Carne, G. Buticchi, M. Liserre, C. Yoon, F. Blaabjerg, "Voltage and Current Balancing in Low and Medium Voltage Grid by means of Smart Transformer", IEEE PES GM 2015, July 2015

Basic Operation of ST: Balancing Voltage and Current

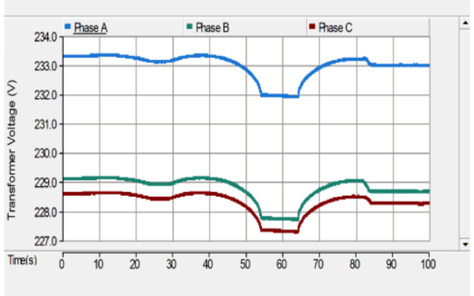
MV Current Traditional Transformer



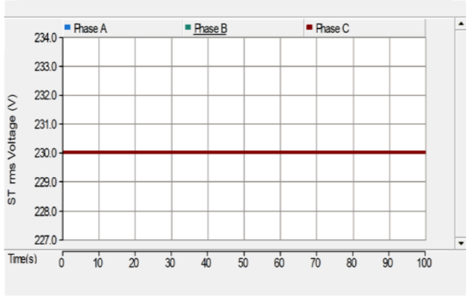
MV Current ST



LV VoltageTraditional Transformer



LV Voltage ST



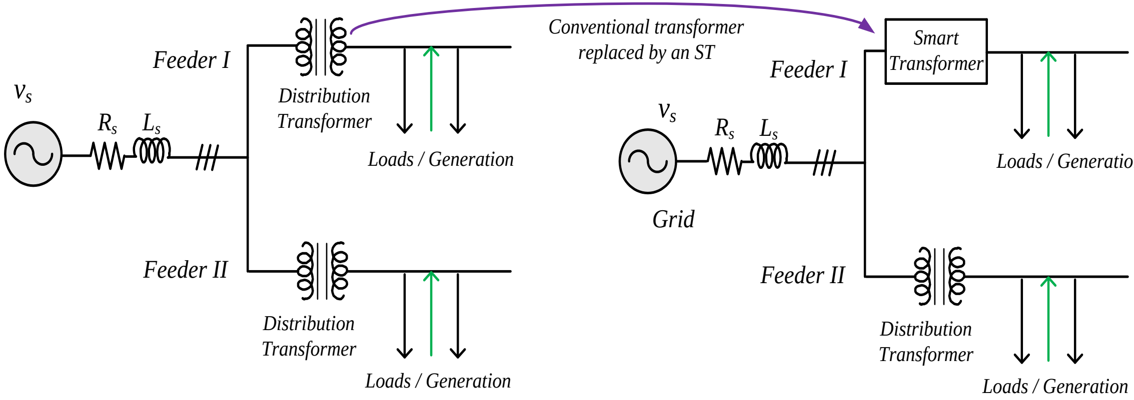
Operation of ST to compensate MV ac grid current

- One CPT is replaced by the ST

- The ST is operated such that it makes total MV grid currents of the combined system balanced sinusoidal with unity power factor.

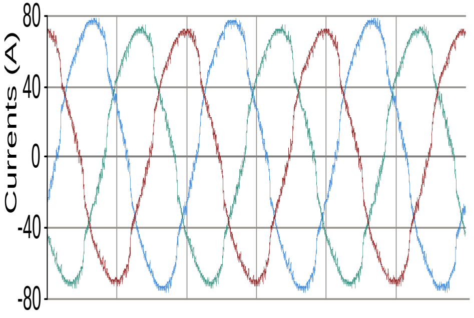
- Harmonic compensation

- Reactive current compensation

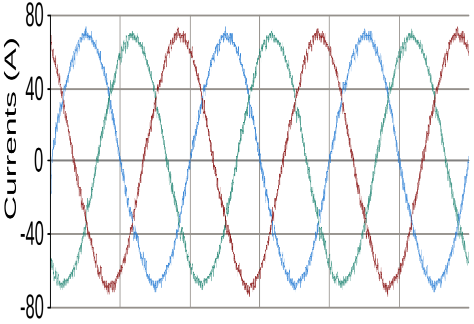


(a) Conventional Power System

(b) Proposed Power System



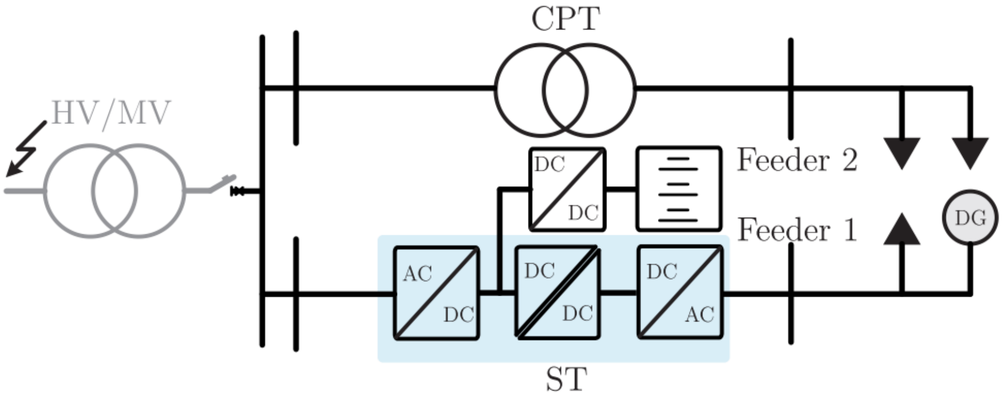
Unbalanced distorted MV grid currents in conventional scheme



Balanced sinusoidal MV grid currents in proposed scheme

C. Kumar and M. Liserre, "Operation and control of smart transformer for improving performance of medium voltage power distribution system," 2015 IEEE 6th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), 2015, pp. 1-6, doi: 10.1109/PEDG.2015.7223092.

Dual Microgrid with ST



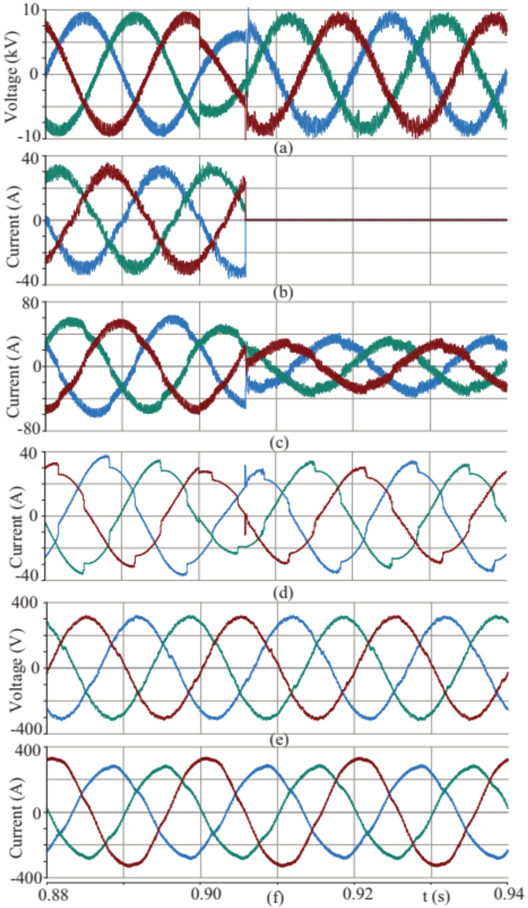
Dual microgrid enabled with ST

- In normal condition, ST supports the feeder-1 loads or exports power from the DG connected at feeder-1
- During grid isolation, ST MV converter operates in voltage control mode to supply essential loads at feeder-2

C. Kumar and M. Liserre, "A new prospective of smart transformer application: Dual microgrid (DMG) operation," IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society, 2015, pp. 004482-004487, doi: 10.1109/IECON.2015.7392798.

Dual Microgrid with ST

- During grid isolation, ST MV converter changes to voltage control mode from grid following current control mode
- ST dc-dc converter controls the MV dc link voltage
- LV dc link voltage is maintained by the renewable sources connected



MV ac bus voltages

MV ac grid currents

ST MV ac currents

Total feeder-2 currents

Feeder-1 LV ac voltages

Feeder-1 LV ac currents

ST-based Low Voltage Meshed Hybrid Microgrid

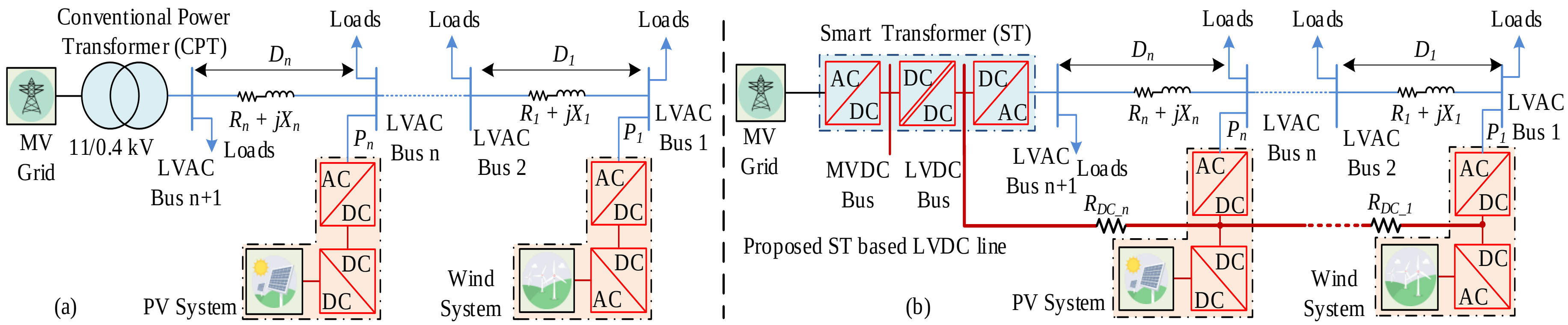


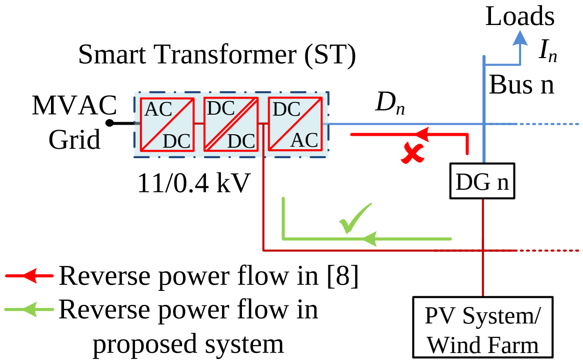
Fig. (a) CPT based hybrid microgrid (b) ST based meshed hybrid microgrid

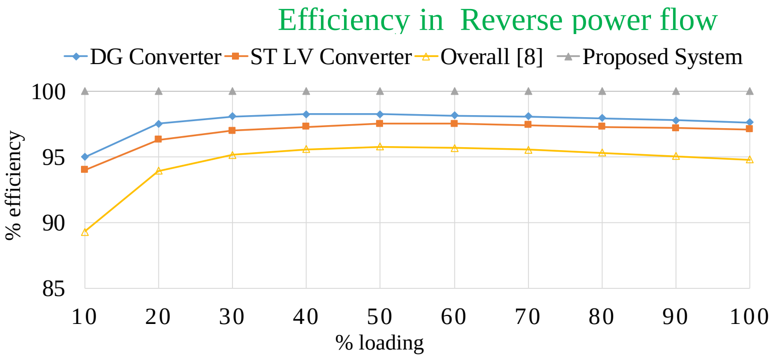
- DG converters usually rated for maximum output of renewable source
- PV/Wind power are highly intermittent
- DG converters are underutilized at most times
- Load on transformer increases during absence of renewable power

- Improved utilization of DG converters
- Reduction in size of ST LV converter
- Reduction of distribution losses
- Improved LVAC line voltage profile
- Reduced converter losses during reverse power flow

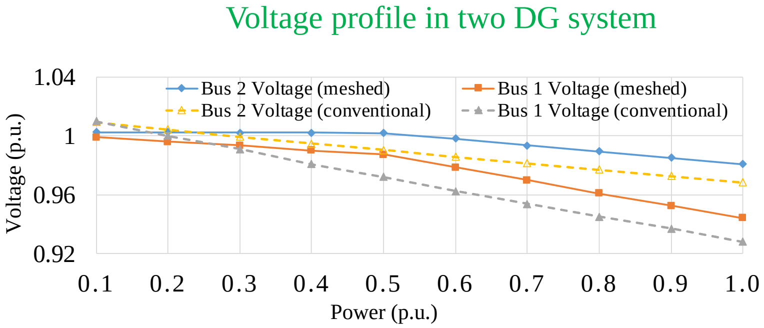
D. Das, V. M. Hrishikesan, C. Kumar and M. Liserre, "Smart Transformer-Enabled Meshed Hybrid Distribution Grid," ***in IEEE Transactions on Industrial Electronics***, vol. 68, no. 1, pp. 282-292, Jan. 2021

ST-based Low Voltage Meshed Hybrid Microgrid



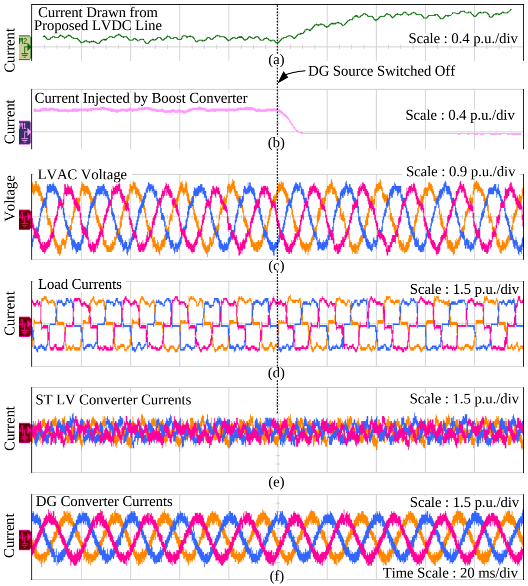


- Improved AC voltage profile
- DG converters supply only active power in proportion to their rating
- ST LV converter supplied reactive and harmonic power requirement of load

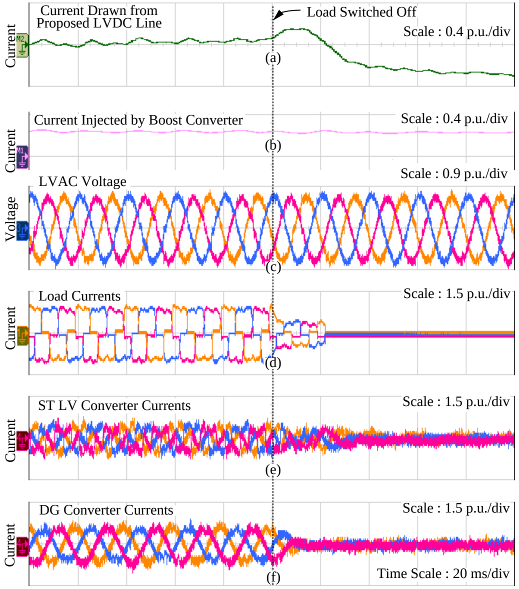


Experimental Results

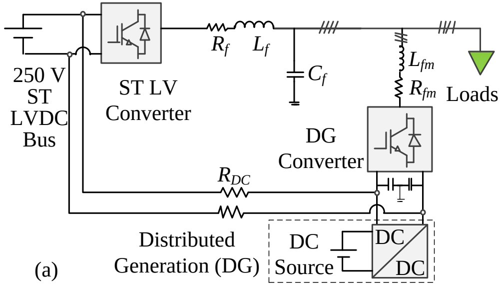
- DC source with DC-DC converter is used as DG source.
- During absence of DG source, more power is drawn from the grid through LVDC line
- Once load is removed, the DG power is fed to MVAC grid through LVDC line



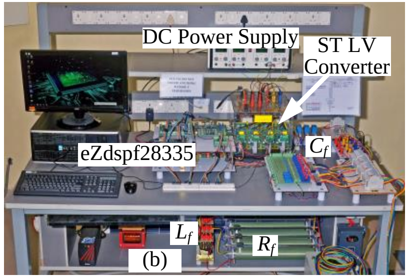
Experimental results for absence of DG source



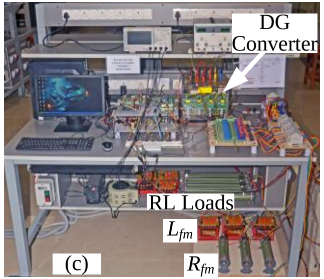
Experimental results for reverse power flow



(a)



(b)

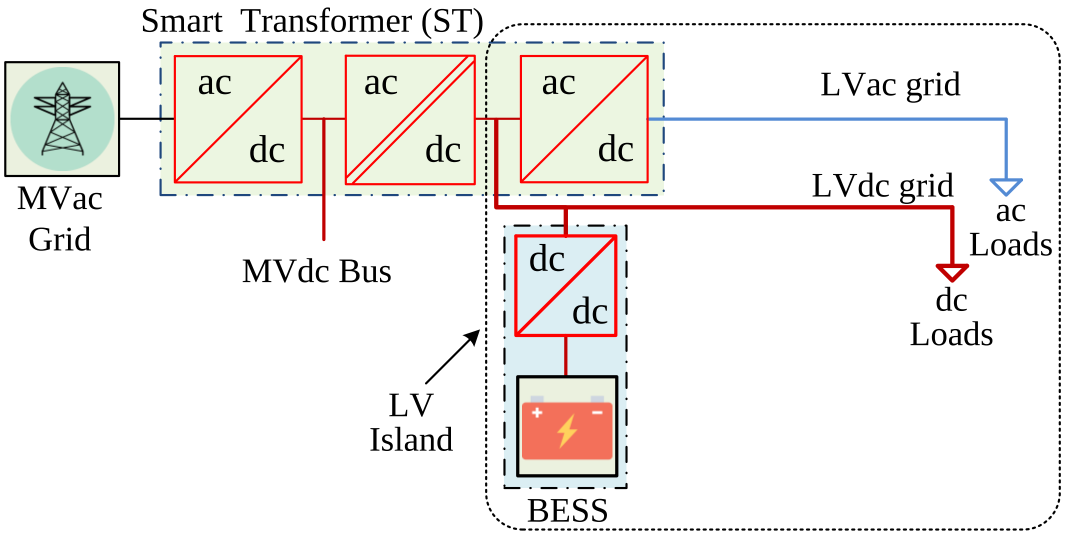


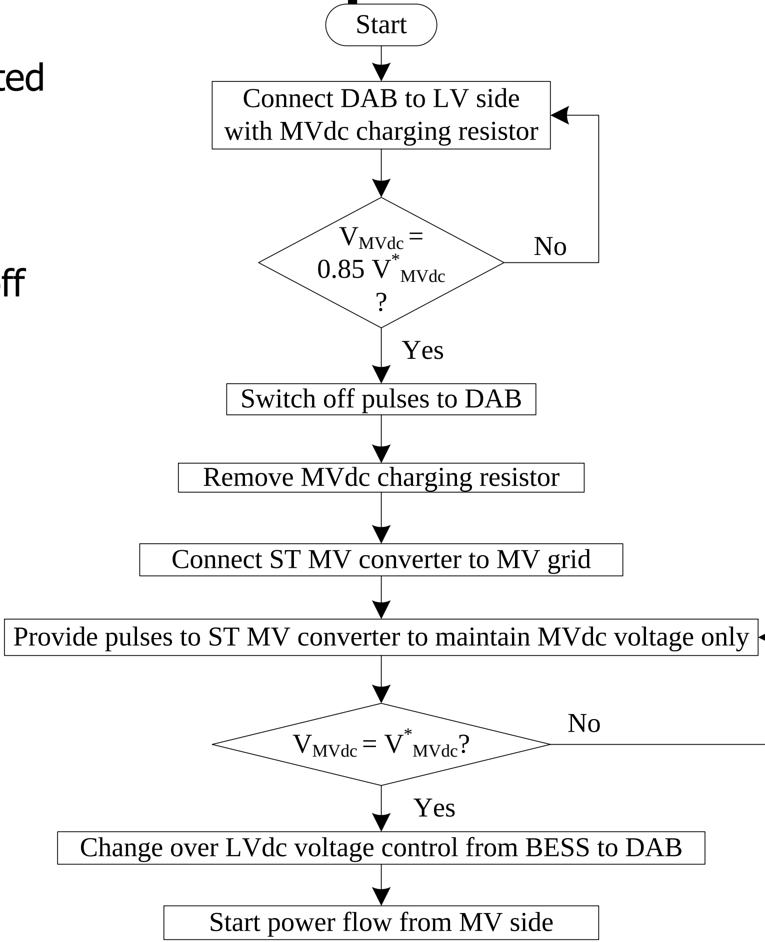
(c)

(d)

Partial Start-up of ST in Meshed Hybrid Islanded Grid Operation

- With sufficient storage, the ST based meshed grid can be supported during disconnection from MVAC grid
- A proper starting mechanism is necessary for re-connection from islanded mode
- In islanded mode, ST MV and ST DC-DC isolated converters are off
- 3 stage connection to MVAC grid operation is proposed





Start

Connect DAB to LV side with MVdc charging resistor

$V_{MVdc} = 0.85 V^*_{MVdc}$?

No

Yes

Switch off pulses to DAB

Remove MVdc charging resistor

Connect ST MV converter to MV grid

Provide pulses to ST MV converter to maintain MVdc voltage only

$V_{MVdc} = V^*_{MVdc}$?

No

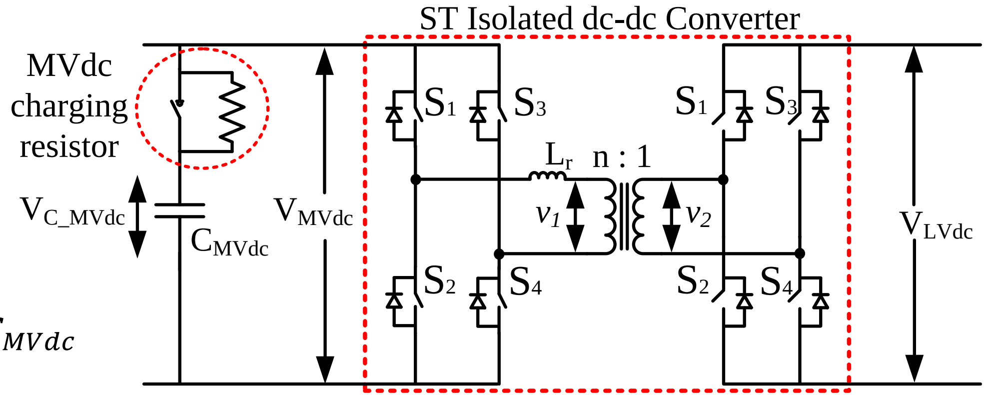
Yes

Change over LVdc voltage control from BESS to DAB

Start power flow from MV side

D. Das and C. Kumar, "Partial Startup Scheme for Smart Transformer in Meshed Hybrid Islanded Grid Operation," ***in IEEE Transactions on Industry Applications,*** vol. 58, no. 1, pp. 142-151, Jan.-Feb. 2022

Three stage start-up process



Stage I - Charging of MVdc Bus till 0.85 V*MVdc

Expression for capacitor charging

$$V_{C\_MVdc} = V_{MVdc}\left\{1 - e^{\left(-\frac{t}{R_{MVdc}^{charge}\times V_{MVdc}}\right)}\right\}$$

Time required for charging: $t = 1.897\times R_{MVdc}^{charge} \times C_{MVdc}$

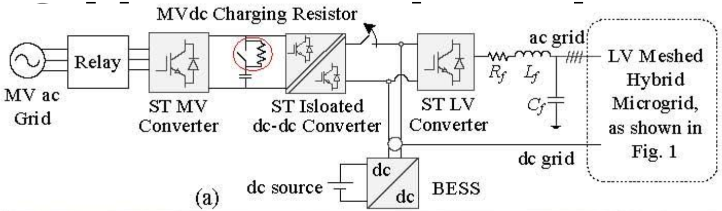
Stage II - Charging of MVdc Bus till V_{MVdc}^{*}

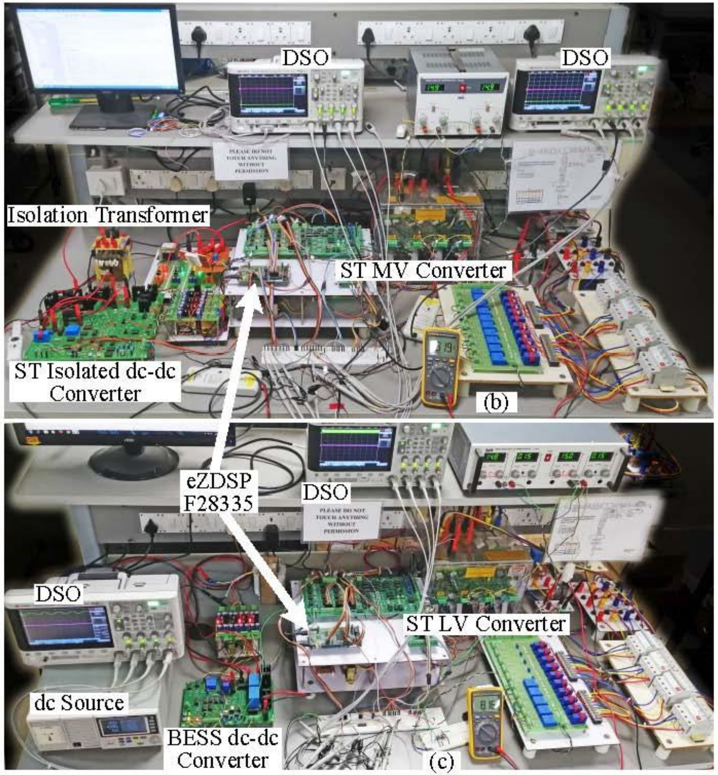
- ST MV converter is turned on
- power drawn by the ST MV converter is only to charge the ST MVdc bus
- Hard limit for reference currents is given based on rating

Stage III - Changeover of LVdc Control

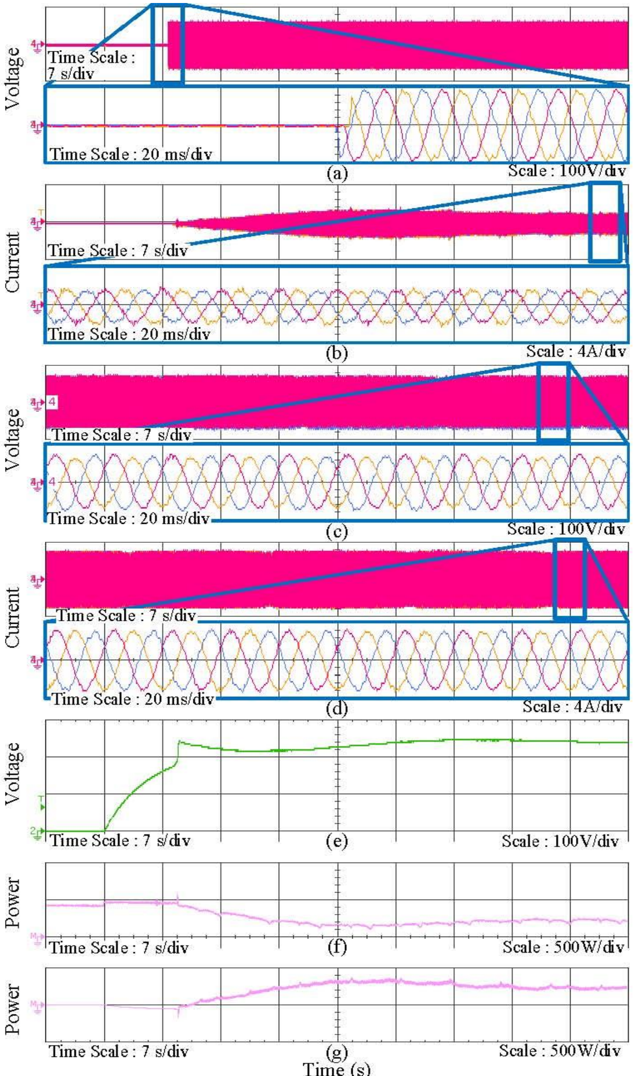
- BESS dc-dc converter mode is converted from VCM to CCM
- Simultaneously ST isolated dc-dc converter is again turned on
- BESS power injection is limited to a fixed value

Results: Islanded to Steady state operation





(a) ST MVac voltage. (b) MVac current. (c) LVac voltage. (d) LVac current. (e) MVdc voltage. (f) BESS power output. (g) ST isolated dc–dc converter/DAB power output.



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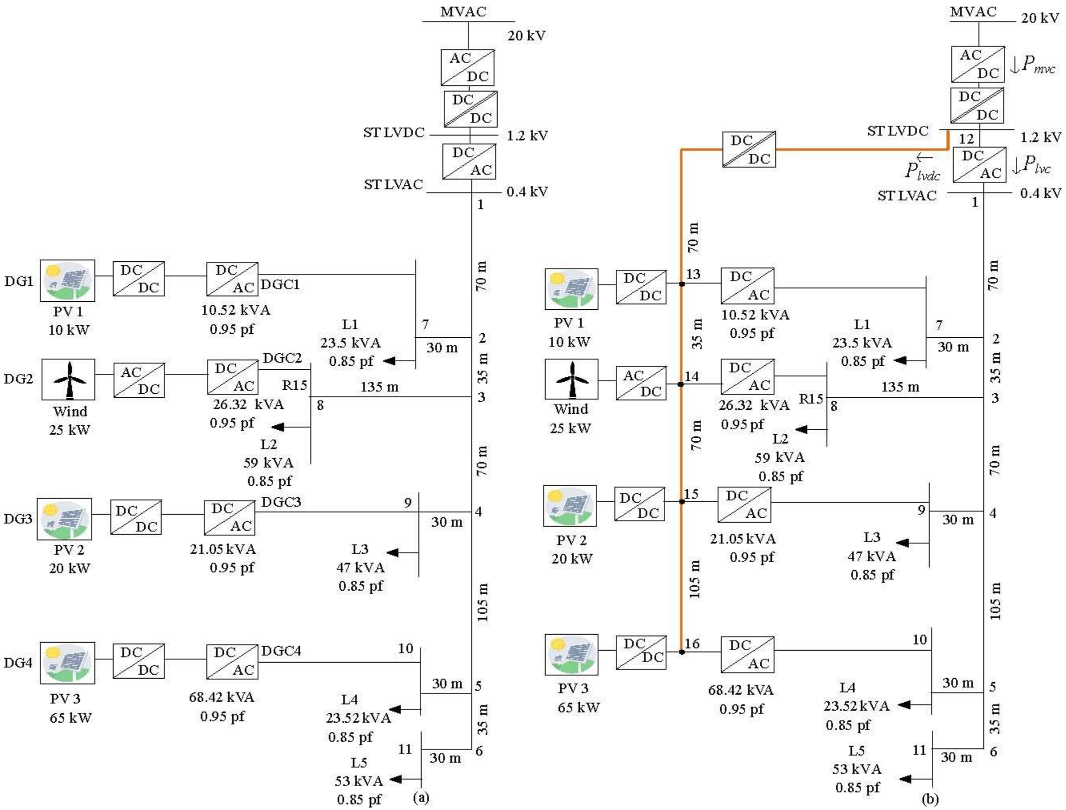
Optimal Control of DG Converters in ST based Meshed Grid

- An optimal problem is formulated for determining the active and reactive power references of DG converters while maintaining the LVAC load bus voltages within the grid limits.

- The minimization of energy drawn from ST medium voltage (STMV) grid is considered as objective function and solved using genetic algorithm.

- To know the impact of proposed optimal control of DG converters, various performance indicators i.e., energy loss, operating energy costs, voltage profile and sizing of ST converters are considered and compared with existing literature.



Chandan Kumar, Rampelli Manojkumar, Sanjib Ganguly, Marco Liserre, “Impact of Optimal Control of Distributed Generation Converters in Smart Transformer Based Meshed Hybrid Distribution Network" ***IEEE Access Journal***, vol. 9, pp. 140268-140280, 2021,

Optimal Control of DG Converters in ST based Based Meshed Grid

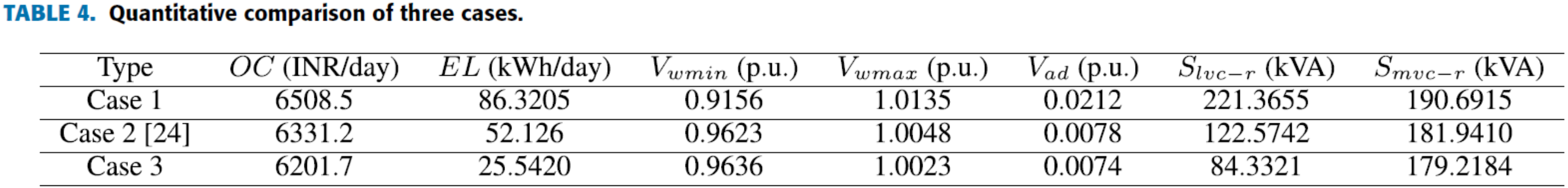


TABLE 4. **Quantitative comparison of three cases.**

Type	OC (INR/day)	EL (kWh/day)	V_{wmin} (p.u.)	V_{wmax} (p.u.)	V_{ad} (p.u.)	S_{lvc-r} (kVA)	S_{mvc-r} (kVA)
Case 1	6508.5	86.3205	0.9156	1.0135	0.0212	221.3655	190.6915
Case 2 [24]	6331.2	52.126	0.9623	1.0048	0.0078	122.5742	181.9410
Case 3	6201.7	25.5420	0.9636	1.0023	0.0074	84.3321	179.2184

Case 1: CPT based system; **Case 2:** ST based meshed grid; **Case 3:** ST based grid with optimal control

- The obtained results show that the energy loss (EL) and operating energy costs (OC) are reduced by 30.8% and 1.99%, respectively over a day using the proposed method as compared to the case when DG converters supply only active power as per Case 2.

- Better system voltage profile is obtained with proposed method as compared to other methods.

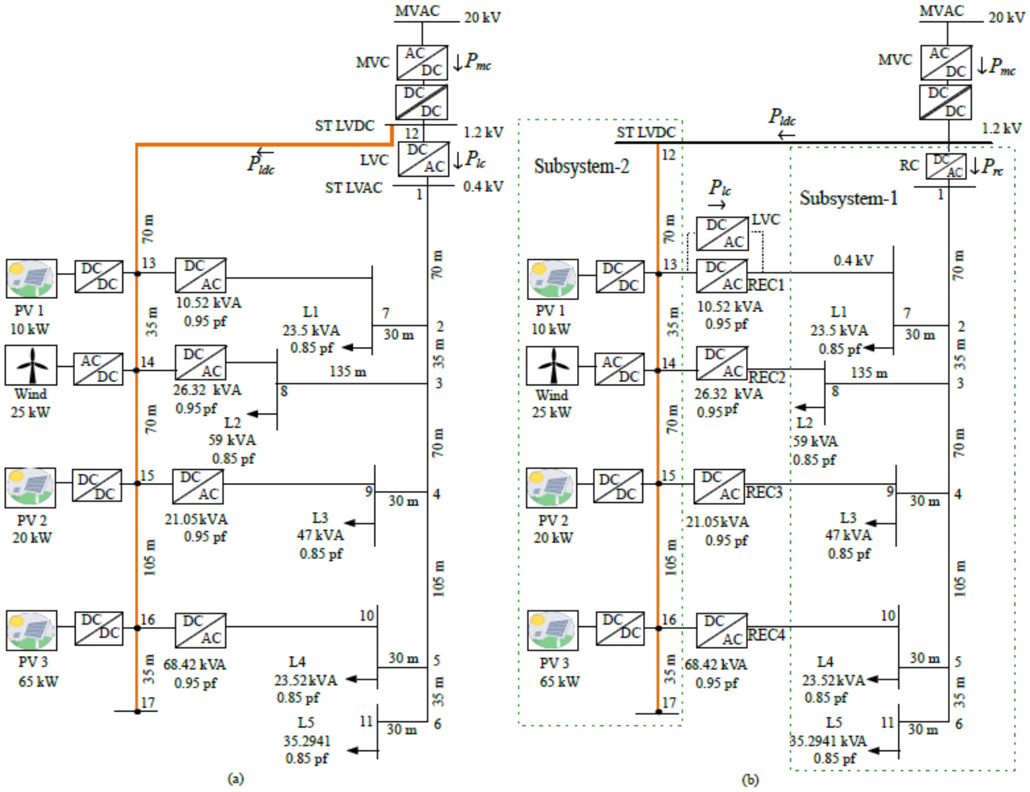
- The LV converter and MV converter sizes are reduced by 17.27% and 1.43%, respectively using the proposed method as compared to the case when DG converters supply only active power as per Case 2.

Optimal Placement of Smart Transformer Low Voltage Converter

- The existing ST configurations use fixed location for installation of ST low voltage (LV) converter as grid forming converter.

- This may not provide the optimal performance of overall system.

- However, the location of LV converter can be decided optimally. The new LVC location from among the all the possible locations is determined such that maximum energy loss reduction is achieved over a day.

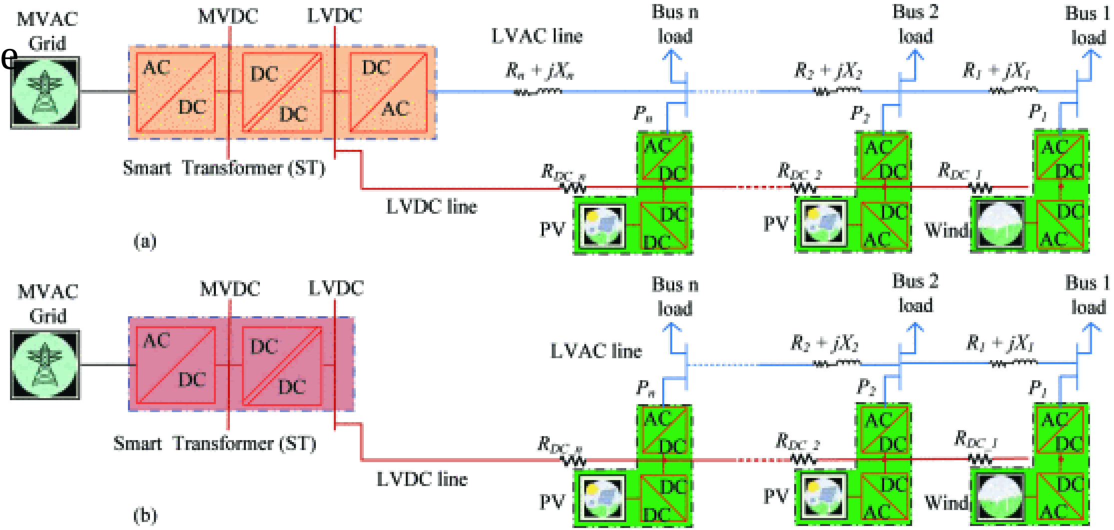


Chandan Kumar, Rampelli Manojkumar, Junru Chen Sanjib Ganguly, Marco Liserre, “Energy Loss Reduction in Meshed Distribution Systems with Optimal Placement of Smart Transformer Low Voltage Converter”

Two-Stage Smart Transformer in Meshed Hybrid Distribution Grid

- Three-stage ST based system
  - LV converter supports active, reactive and harmonic powers
  - DG requires communication
  - Rated ST LV converter

- Two-stage ST based system
  - ST LV converter not required
  - DG converters operates in droop mode
  - No requirement of communication among converters



(a) Three-stage ST-based meshed hybrid distribution grid. (b) Two-stage ST-based meshed hybrid distribution grid.

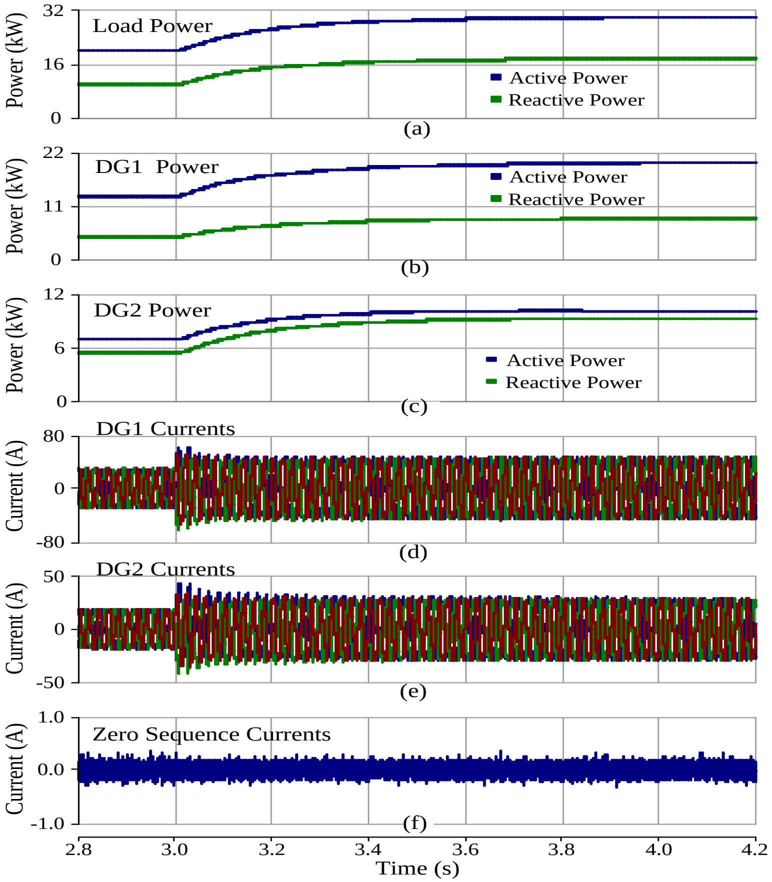
C. Kumar, V. M. Hrishikesan, D. Das and S. Ghosh, "Control and Sizing of Two-Stage Smart Transformer in Meshed Hybrid Distribution Grid," ***2020 IEEE 9th International Power Electronics and Motion Control Conference (IPEMC2020-ECCE Asia),*** 2020, pp. 2129-2134,

Simulation Results

- Two converter system is considered
- Total real and reactive loads are initially 20 kW and 10 kVAr,
- Total real and reactive loads are increased to 30 kW and 17 kVAr, respectively.

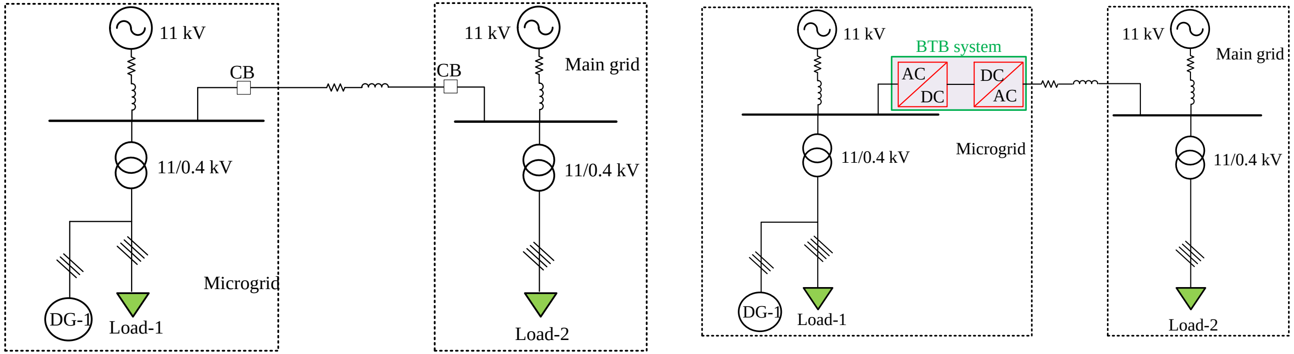
- Load share for each DG converter increases accordingly

- The circulating current control algorithm suppresses the zero sequence currents



MVDC Based Meshed Hybrid Microgrid Enabled Using STs

Conventional system configuration to connect two grids

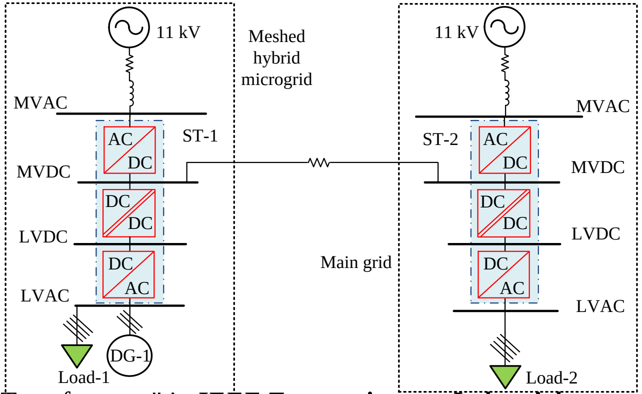


(a)

(b)

- BTB system introduces controlled power flow
- AC lines converted to MVDC line
- ST-based system with MVDC interconnection

Proposed configuration to connect two grids

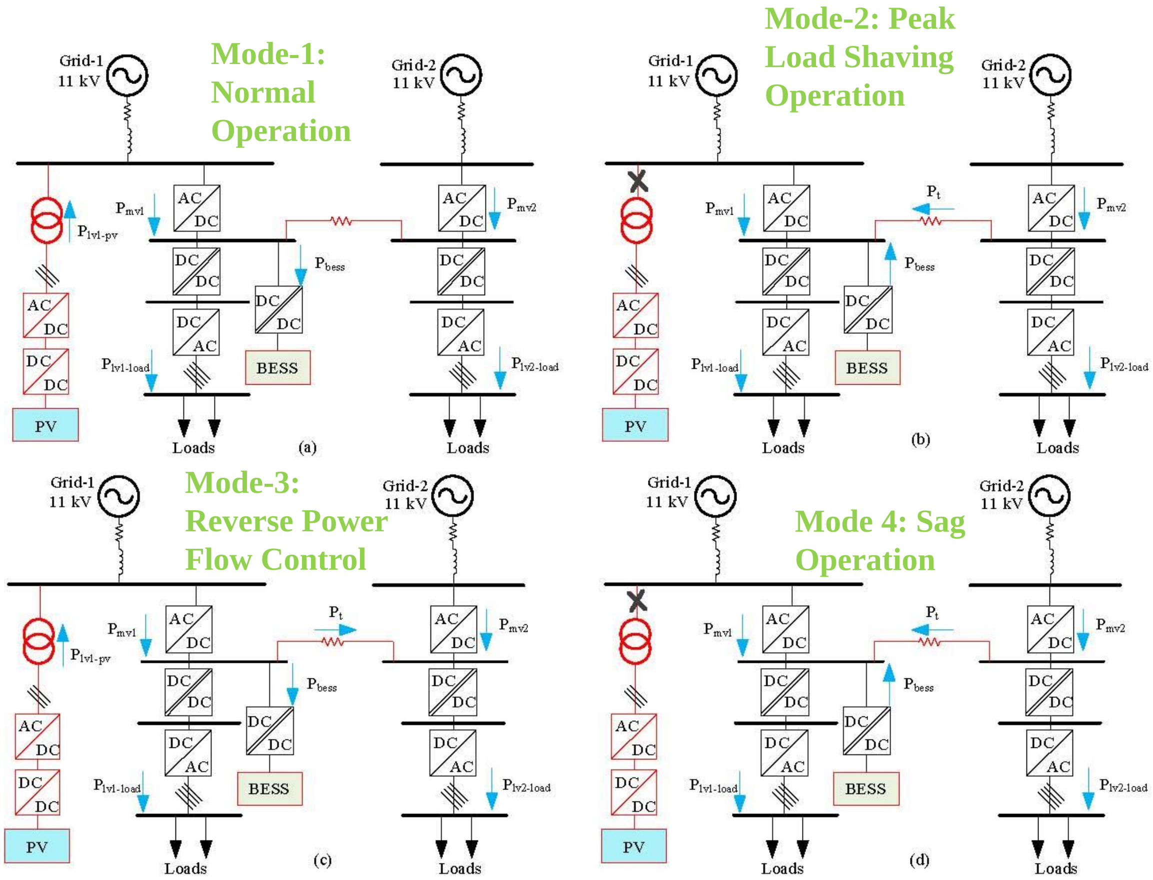


- Lower line loss during inter-grid power transfer
- Higher reactive power capability
- High flexibility in inter-grid active power transfer
- Uninterrupted LVAC bus operation during MVAC failure

V. M. Hrishikesan, C. Kumar and M. Liserre, "An MVDC-Based Meshed Hybrid Microgrid Enabled Using Smart Transformers," in ***IEEE Transactions on Industrial Electronics***, vol. 69, no. 4, pp. 3722-3731, April 2022, doi: 10.1109/TIE.2021.3071683.

Performance during adverse grid conditions

- lower peak power demand from MVAC grid smooths the load curve and reduces the unmanageable high-load conditions on the grid
- Reverse power flow control reduces the voltage rise conditions without the PV active power curtailment, and this helps in maximizing the energy extraction from PV sources
- continuous operation of loads during grid voltage sags are helpful in reducing power interruption-hours in the system and this improves the reliability of power supply to the customer.



Mode-1: Normal Operation

Mode-2: Peak Load Shaving Operation

Mode-3: Reverse Power Flow Control

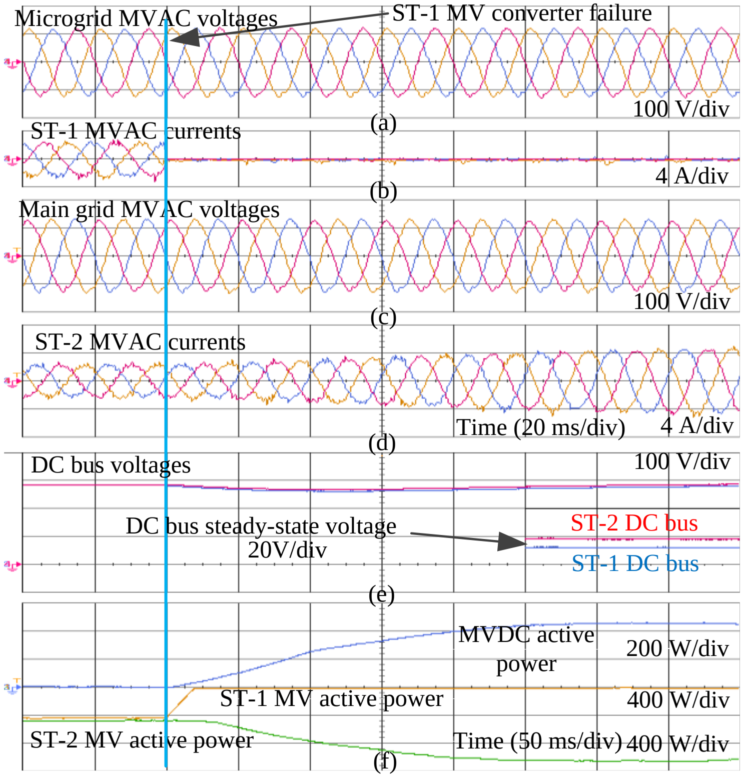
Mode 4: Sag Operation

V. M. Hrishikesan and C. Kumar, "Operation of Meshed Hybrid Microgrid During Adverse Grid Conditions With Storage Integrated Smart Transformer," in ***IEEE Open Journal of the Industrial Electronics Society***, vol. 2, pp. 315-325, 2021

Experimental Results

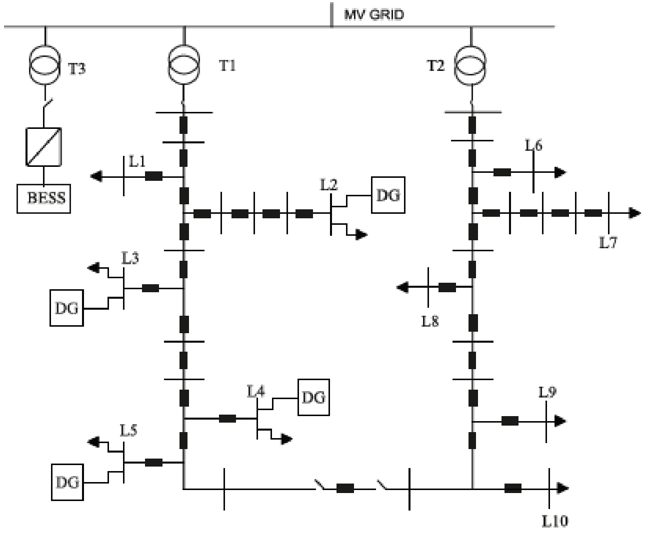
- During failure of ST-1 MV converter, its currents become zero. The power required at its LV side load is supplied by ST-2 MV converter. The dc-link voltage of ST-2 remains high to facilitate the transfer.

Experimental results during ST-1 MV converter failure

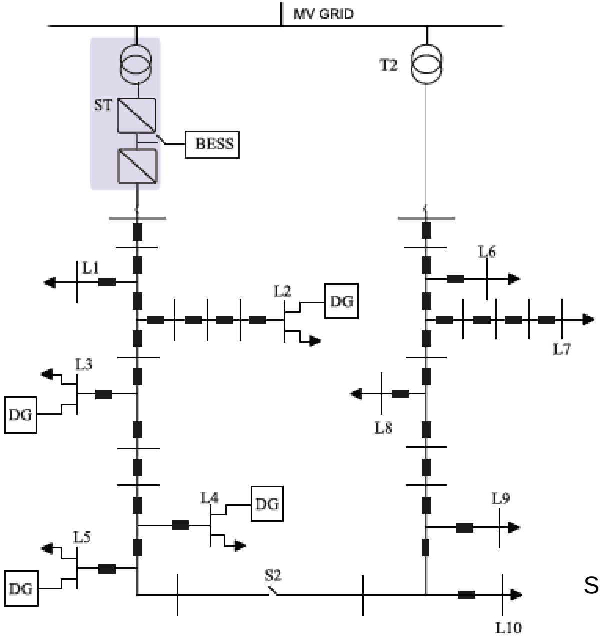


ST as loop power flow controller (LPFC)

- CPT of feeder 2 may be overloaded during the peak load demand with significant voltage reduction at the end of the feeder
- Feeder 1 CPT may get overloaded during the peak DG power generation with increase in feeder voltage
- With this type of voltage profile, it is difficult for power utility to set the voltage at the medium voltage grid for satisfactory operation of the distribution grid



Conventional LPFC

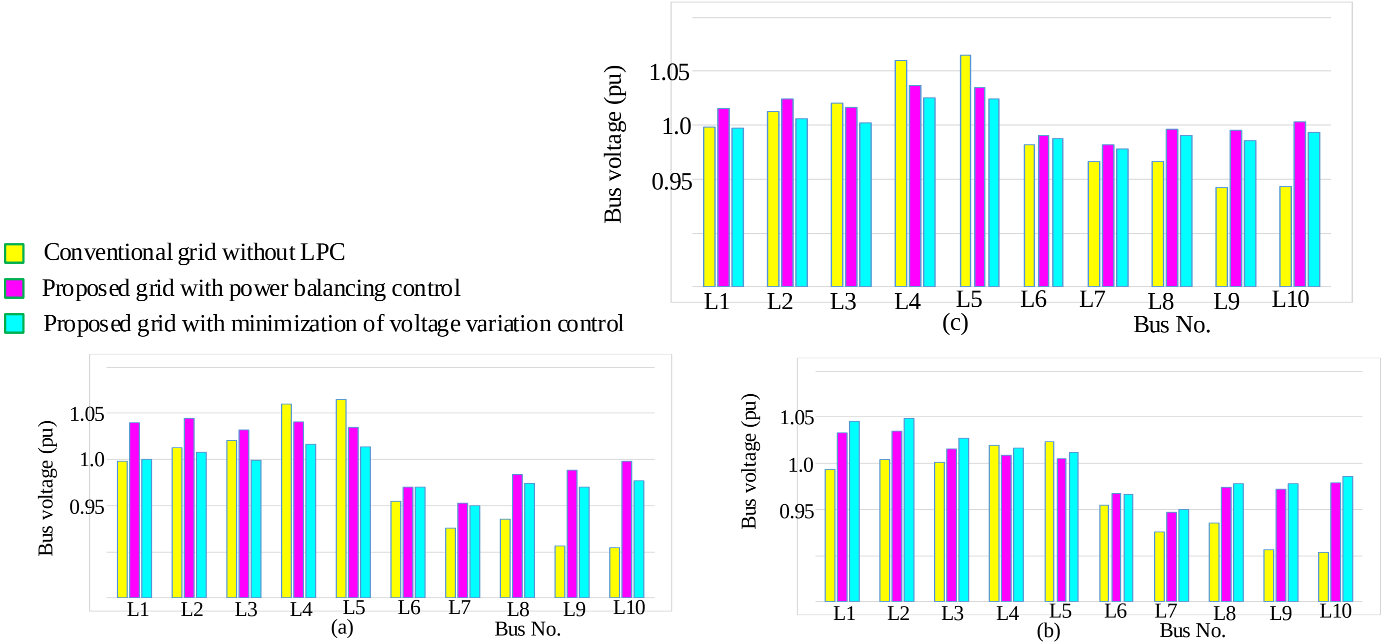


ST based LPFC

C. Kumar, X. Gao and M. Liserre, "Smart Transformer Based Loop Power Controller in Radial Power Distribution Grid," 2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), 2018, pp. 1-6, doi: 10.1109/ISGTEurope.2018.8571844.

ST as loop power flow controller (LPFC)

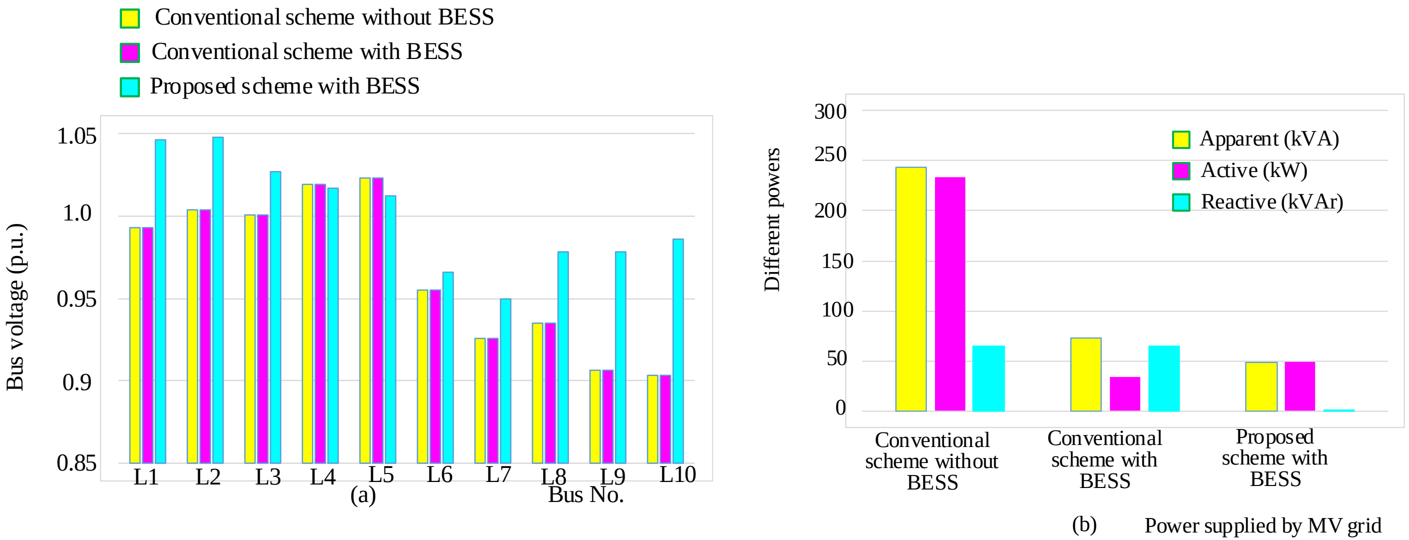
- If **power balancing** cannot maintain voltage within limits **then voltage minimization control** is used



Voltage profile at different buses for different control schemes. (a) High DG penetration and high load demand. (b) Low DG penetration and high load demand. (c) High DG penetration and low load demand.

ST as loop power flow controller (LPFC)

- Both converters of ST are involved in active and reactive power support



(a) Voltage profile at different buses for different control schemes (b) MV grid powers

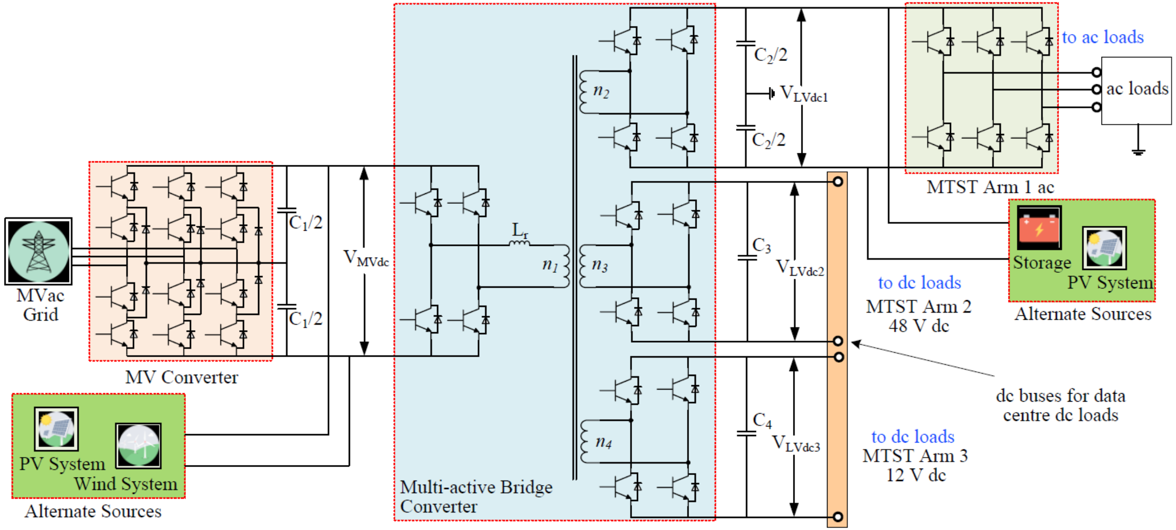
Multi-Terminal Smart Transformer for Green Data Centres

- With the increasing digitalization, cloud servers and data centres have gained significant attention. Renewable energy sources (RES) and battery energy storage systems (BESS) are inherent components of green data centres. This has led to an increasing need to develop efficient power electronic solutions.

- A multi-terminal smart transformer (MTST) is proposed for green data centre applications. The proposed system has the capacity to provide quality power both in the form of ac and dc at various required voltage levels.

- Moreover, the ac and dc terminals also offer the possibility of connecting alternative power sources such as RES or BESS.

- There will be a reduction in the number of power conversion stages which leads to lower losses.

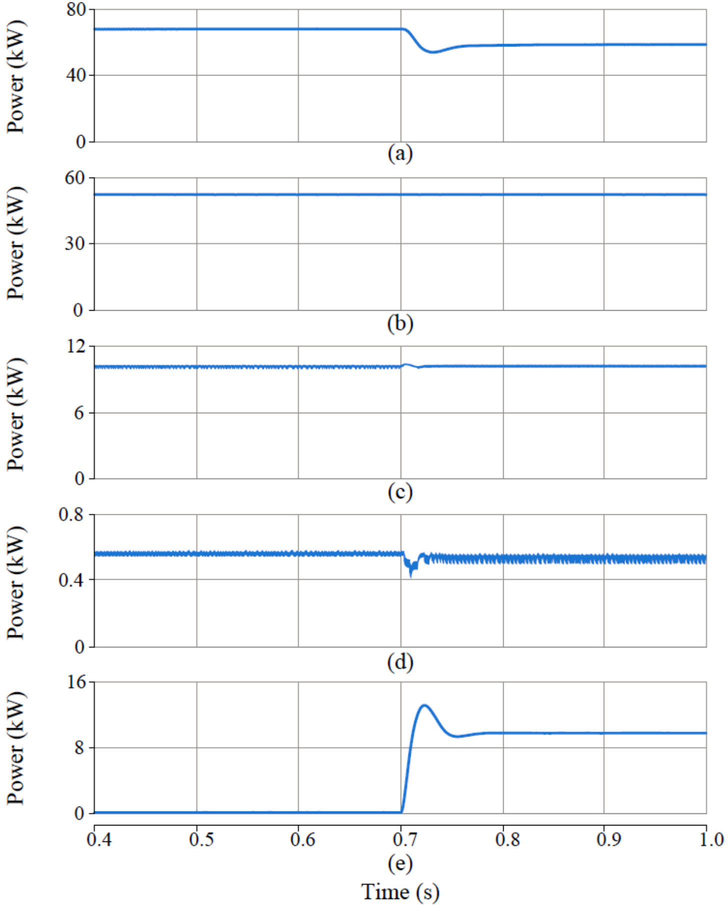


Dwijasish Das, Anandh N, Chandan Kumar, "Multi-Terminal Smart Transformer for Green Data Centres," ***IEEE 13th International Symposium on Power Electronics for Distributed Generation Systems (PEDG),*** June 26th - 29th, 2022 in Kiel, Germany

Multi-Terminal Smart Transformer for Green Data Centres

- Initially the PV source at the 1 kV LVdc is not supplying any power and 66 kW power is drawn from
- the MVac grid. The total LVac load is 53 kW, load at 48 V dc bus is 12 kW and the load at 12 V dc bus is 500 W.

- At t = 0.7 s, the PV system starts supplying 10 kW of power. Thus the power drawn from MVac grid comes down to 56 kW. The remaining load flows remain unchanged.

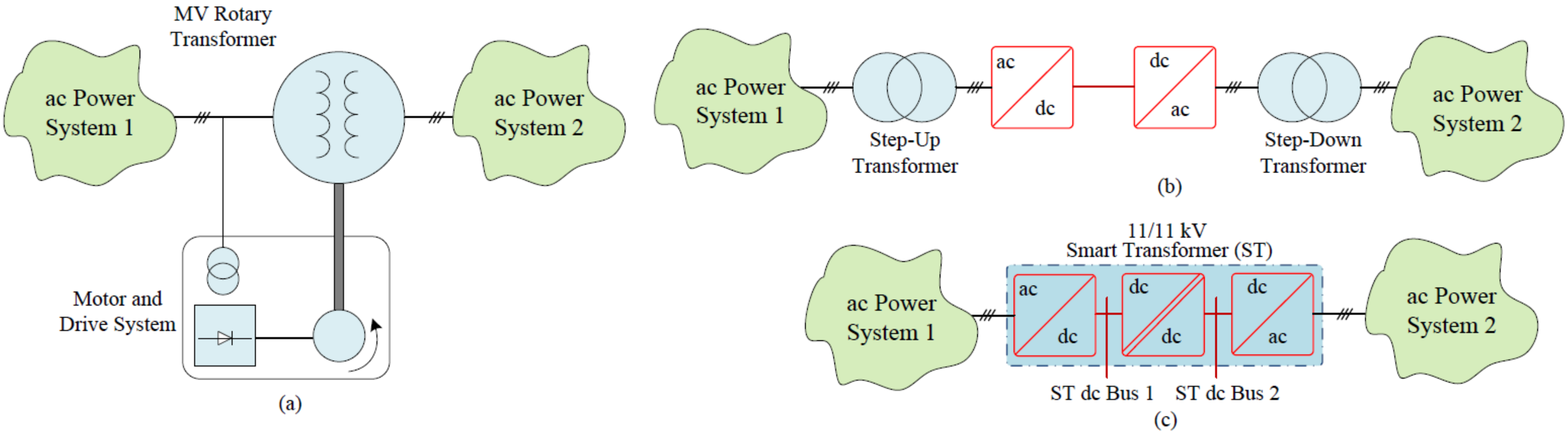


Active power flow in the system. (a) Power drawn from MVac grid. (b) LVac load power. (c) Power drawn from 48 V LVdc bus. (d) Power drawn from 12 V LVdc bus. (e) Power supplied by PV plant to the 1 kV LVdc bus.

Smart Transformer as a Variable Frequency Transformer

- Conventional VFTs are rotational machines working on the principle of induction, and have issues like uncontrolled reactive power flow, high power torque fluctuations, etc. HVDC based system uses transformer.

- Such issues can be mitigated by using ST as a VFT. Moreover, additional dc links of the ST allow for connection to MVdc grids, renewable energy systems, storage, etc.



Schematic diagram. (a) VFT connecting two systems of different frequency [2]. (b) HVdc asynchronous link [7]. (c) Proposed use of ST as VFT.

Dwijasish Das, Chandan Kumar, "Smart Transformer as a Variable Frequency Transformer," 2021 ***6th IEEE Workshop on the Electronic Grid (eGRID),*** 2021, pp. 01-06

Smart Transformer as a Variable Frequency Transformer

- The ST is used to transfer power between two ac power systems 1 and 2, one operating at 50 Hz and the other operating at 60 Hz.
- Both the ac grids are at a voltage level of 11 kV. Initially a power of 5 MW is transferred from power system 1 to power system 2.
- At t = 0.5 s, the power transfer is reduced from 5 MW to 2 MW.
- This change is seen in the power waveforms and reflects as a reduction in the currents as shown in the results.

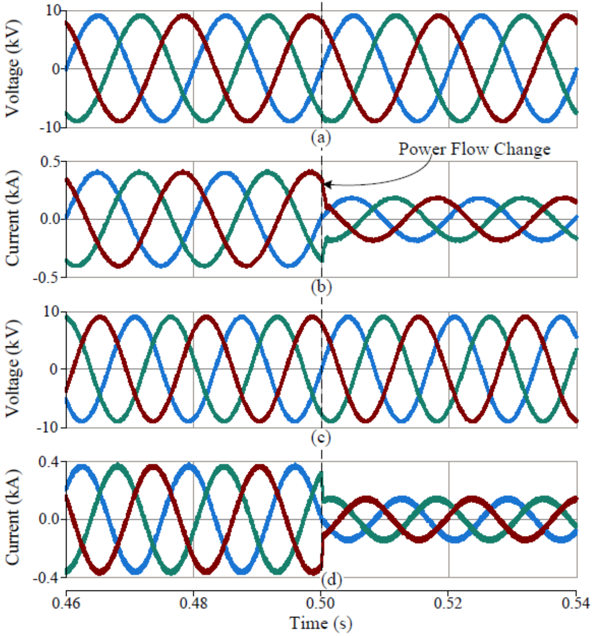


Fig. 3. Ac currents and voltage waveforms. (a) Ac power system 1 voltage. (b) Current drawn from power system 1 (c) Ac power system 2 voltage. (d) Current dlivered to power system 2.

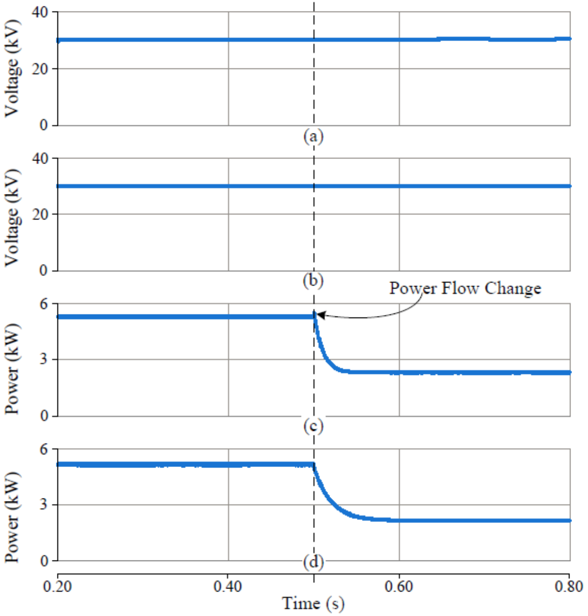
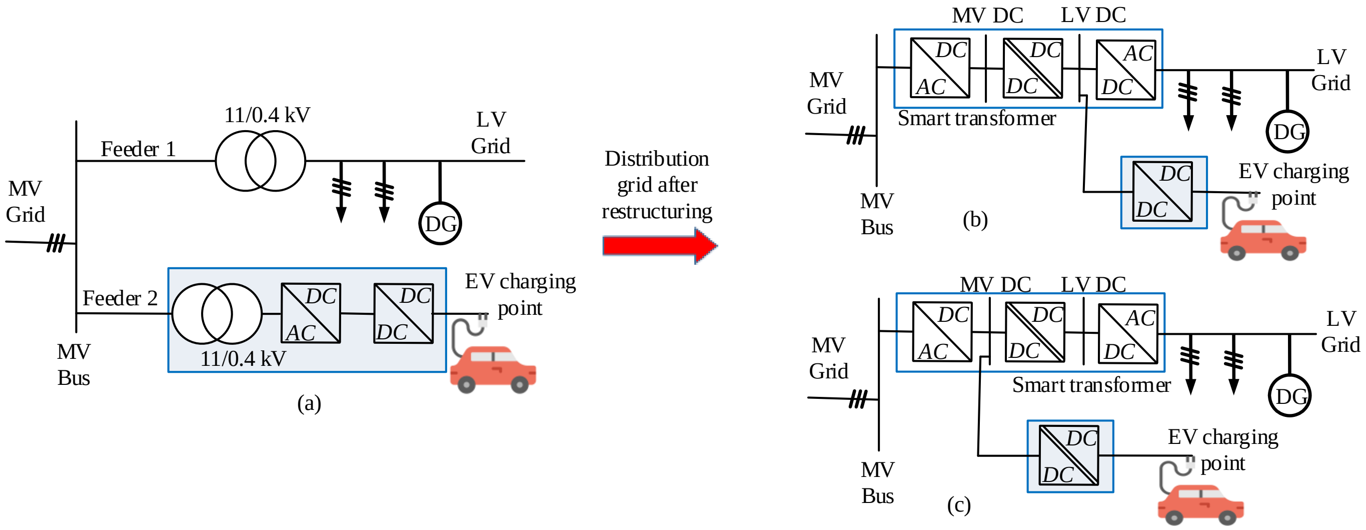


Fig. 4. Simulation dc link voltages and power flow. (a) ST dc link 1 voltage. (b) ST dc link 2 voltage. (c) Power drawn from power system 1. (d) Power delivered to power system 2.

Operation and Control of ST based EV Charging System

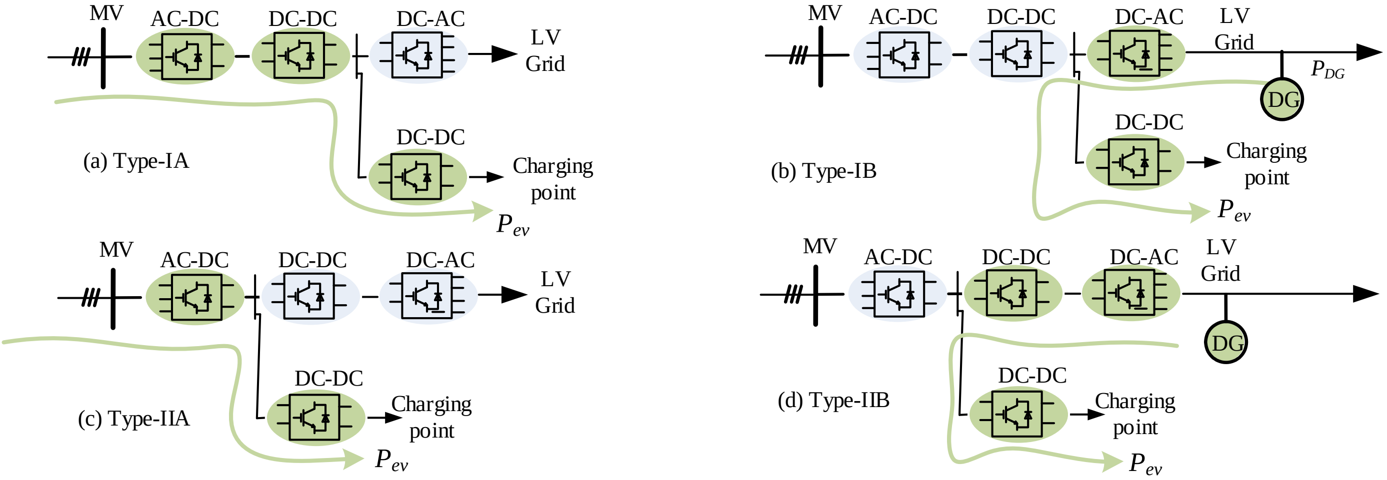
- Instead of connecting EV charging station through CPT, MV and LV DC links of ST can be used for realizing EV charging stations



(a) Traditional distribution grid with loads and EV charging station supported by CPTs. (b) Restructured distribution grid with EV charging station supported by the LV dc link of ST (type-I). (c) Restructured distribution grid with EV charging station supported by the MV dc link of ST (type-II).

Operation and Control of ST based EV Charging System

- The EVs can be charged either from the MV grid or through the DG



Power flow path during charging of EVs for different configurations. (a) Type-IA, charging through MV grid. (b) Type-IB, charging through DG. (c) Type-IIA, charging through MV grid. (d) Type-IIB, charging through DG.

Operation and Control of ST based EV Charging System

- Due to different power flow paths, the efficiency of the charging/discharging will be different

(a) Traditional-A, EV charged through MV grid.

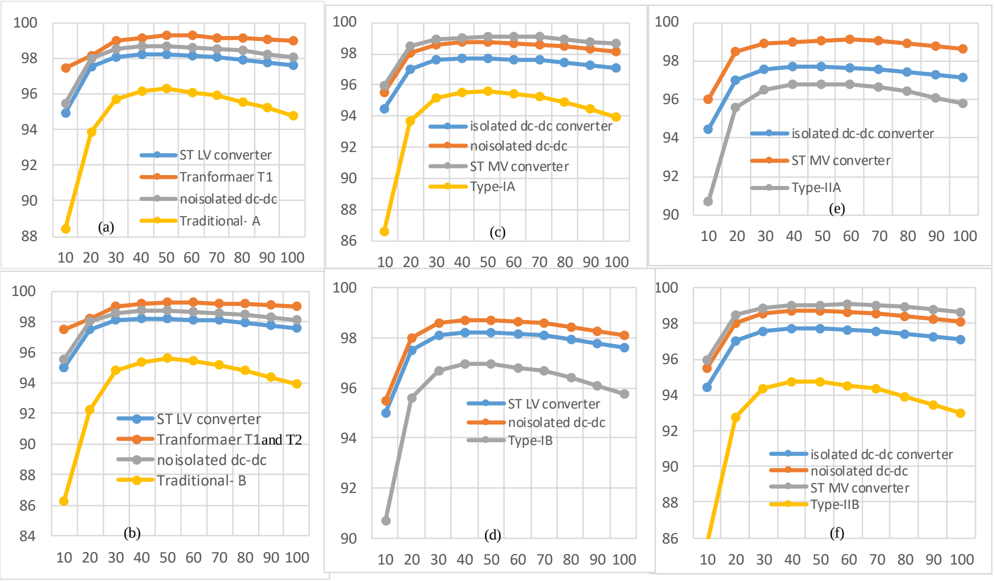
(b) Traditional-B, EV charged through DG.

(c) Type-IA, EV charging through MV grid.

(d) Type-IB, charging through DG.

(e) Type-IIA, EV charging through MV grid.

(f) Type-IIB, EV charging through DG.

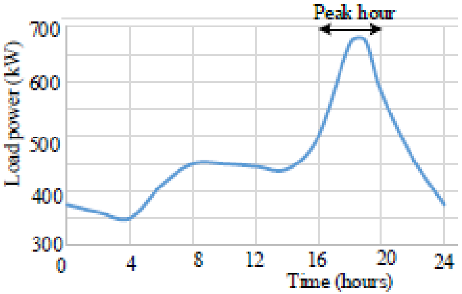


(x-axis: device loading in percentage, y axis: efficiency in percentage).

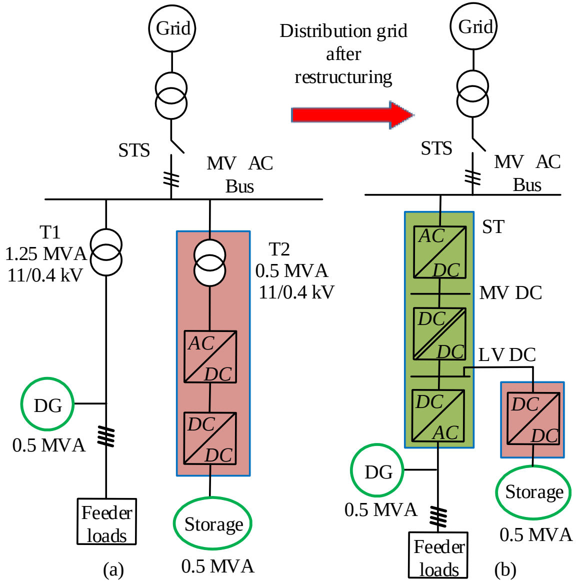
C. Kumar, G. Buticchi and M. Liserre, "Operation and control of smart transformer-based electric vehicles charging system," IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, 2017, pp. 4266-4271, doi: 10.1109/IECON.2017.8216732.

Sizing and SOC-Management of a ST-Based Energy Storage

- DC link of ST can be an effective solution for integrating BESS in electric distribution grid
- Since load demand is low at most of the times, BESS can be used to properly size the ST power converters.



Normalized load profile in a typical residential feeder



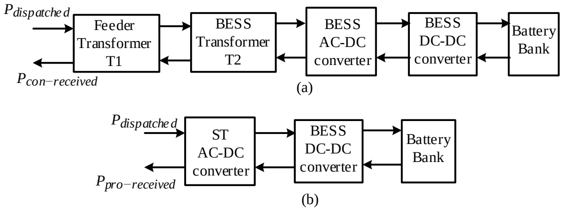
Single line shows. (a) Conventional distribution electric grid. (b) Restructured distribution electric grid with transformer T1 is replaced by an ST and BESS is integrated to LV dc link of ST.

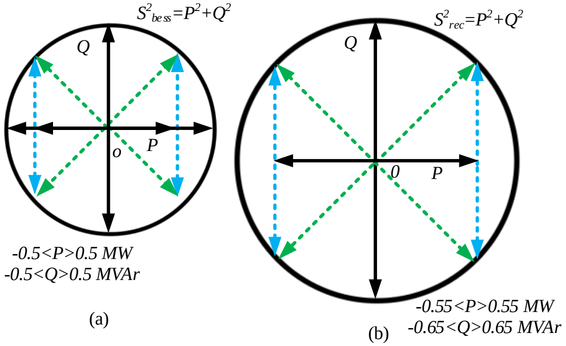
C. Kumar, R. Zhu, G. Buticchi and M. Liserre, "Sizing and SOC Management of a Smart-Transformer-Based Energy Storage System," in IEEE Transactions on Industrial Electronics, vol. 65, no. 8, pp. 6709-6718, Aug. 2018, doi: 10.1109/TIE.2017.2784389.

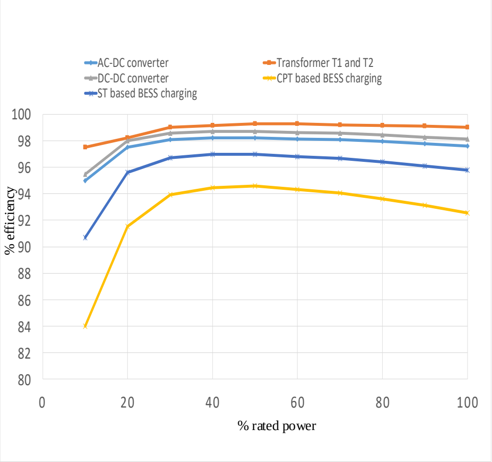
Sizing and SOC-Management of a ST-Based Energy Storage

Efficiency and ancillary services

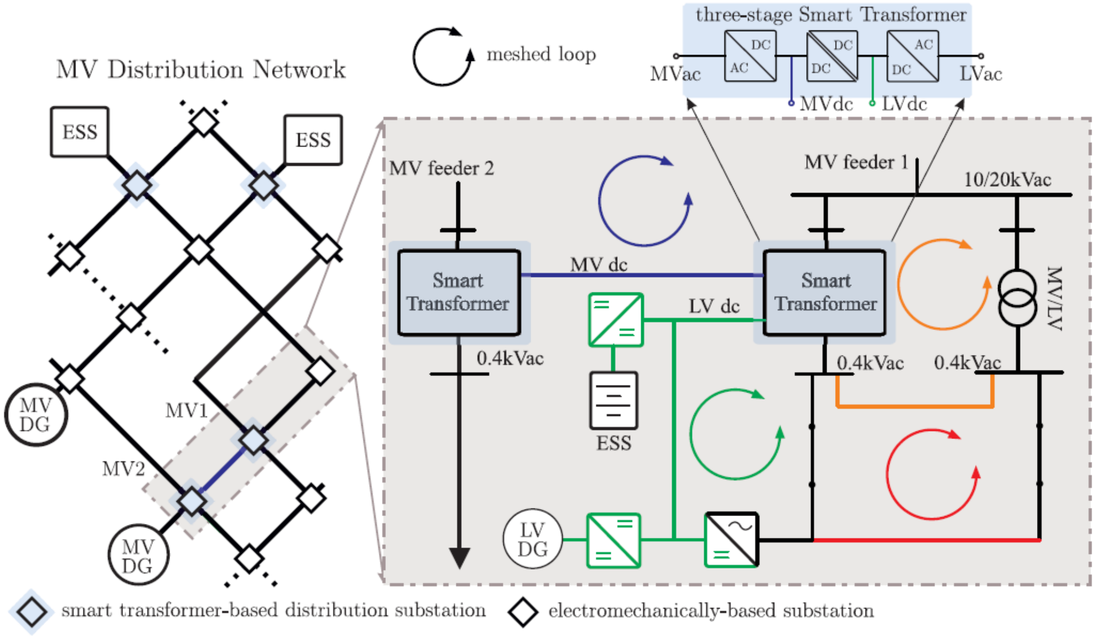
- Efficiency improves due to reduced power flow path
- Greater ancillary services due to increased size MV converter







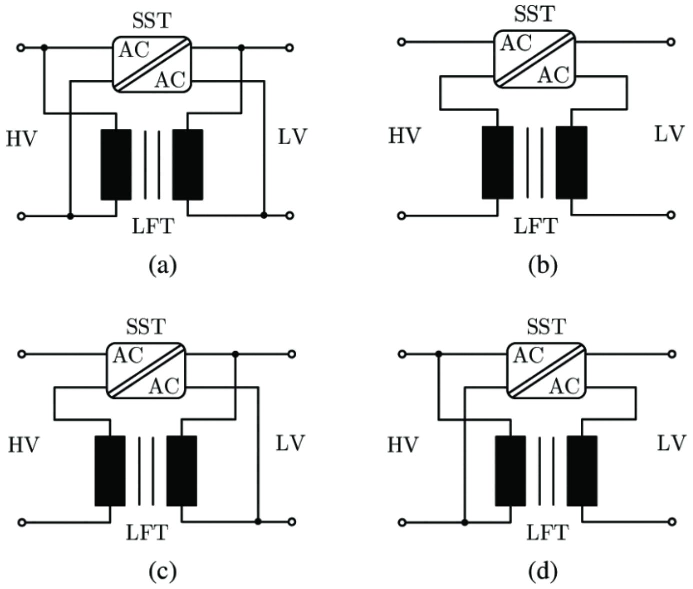
Overview of ST-based Meshed Grids



- Meshed at LV-ac bus bar (orange)
- Meshed in a hybrid way at LV-ac together with LV-dc line (green)
- Meshed through MV-dc line (blue)

R. Zhu, M. Liserre, M. Langwasser and C. Kumar, "Operation and Control of the Smart Transformer in Meshed and Hybrid Grids: Choosing the Appropriate Smart Transformer Control and Operation Scheme," in IEEE Industrial Electronics Magazine, vol. 15, no. 1, pp. 43-57, March 2021, doi: 10.1109/MIE.2020.3005357.

Hybrid SST



Hybrid SST-CPT structures

- **High cost of SST is a concern**
- **CPT-SST hybrid structures are another attractive solution**

Q. Huang, S. Rajendran, S. Sen, Z. Guo, L. Zhang and A. Q. Huang, "500kVA Hybrid Solid State Transformer (HSST): Architecture, Functionality and Control," *2020 IEEE Energy Conversion Congress and Exposition (ECCE)*, Detroit, MI, USA, 2020, pp. 4864-4871

Challenges

- Optimal operation of ST based system for
  - Economical operation
  - Loss minimization
  - Maintaining voltage profile within the limits

- Protection
  - Internal faults of power converters
  - External faults in the electric grid
  - Limited short circuit capacity of power converters
  - Incompatibility between the ST and grid protection system

- Reliability of the system

- Control with or without communication

Thank you