# Maximum Power Tracking among Groups of Distributed Power Sources with Uniform Time/Voltage Distribution Control

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April 2018

# *Motivation for Energy Harvesting among Distributed Power Sources*

- Existing architectures of solar array power systems already adopt distributed solar-array sources:
  - Each array source interfaces with a DC-DC converter, forming a controllable power channel
  - Isolated outputs of distributed power channels are series connected to form a system output voltage
  - The system output voltage is regulated by these distributed-input series-output (DISO) converters.
- Maximum power tracking (MPT) for distributed sources:
  - Their MPT should be simpler without the use of many non-linear MPT controllers, each dedicated for each power source
  - Their peak-power voltages are slowly varied as compared to the MPT response time.

# *Three Approaches of Energy Harvesting*

(1) Draw equal current from each source using uniform current distribution (UCD) control of all distributed sourcing currents,

→ Group-Tracking UCD or GT-UCD

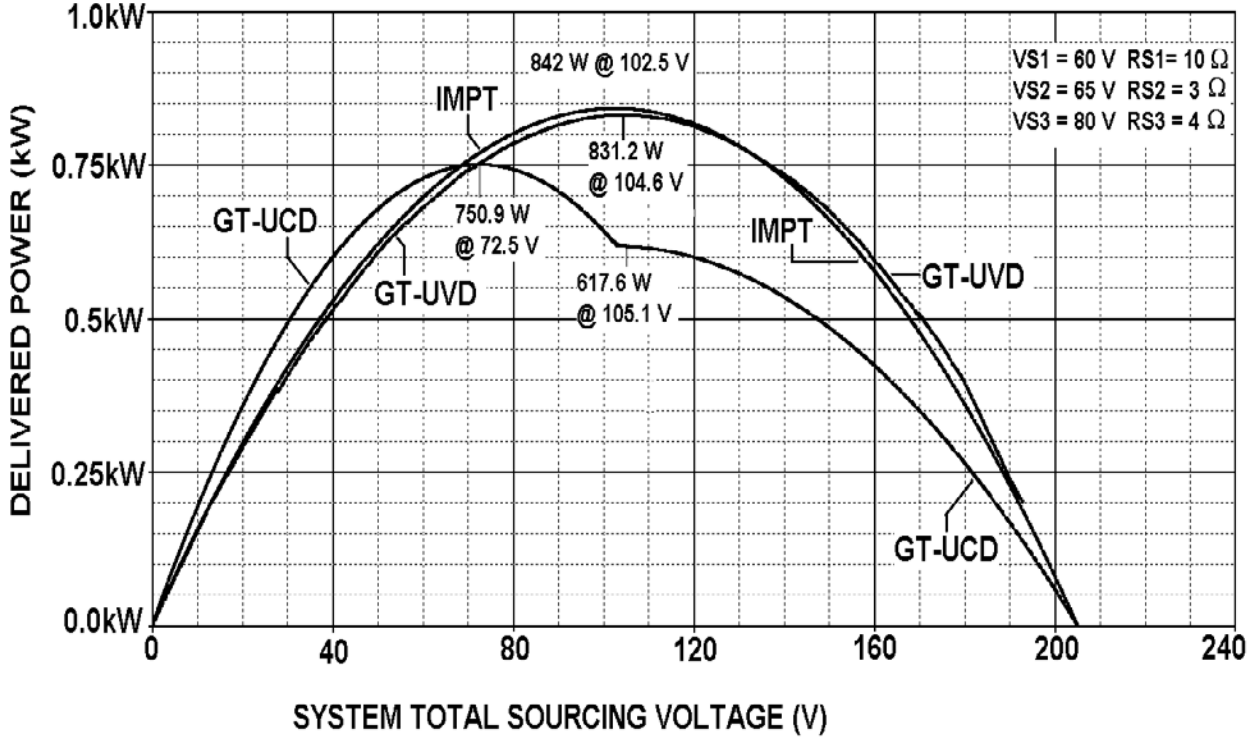
(2) Keep equal voltages across each source using uniform voltage distribution (UVD) control of all distributed source voltages,

→ Group-Tracking UVD or GT-UVD

(3) Independently track peak-power voltage of each source using independent maximum power tracking (IMPT) controllers, each of which is dedicated to each source.

→ IMPT

# *P-V CHARACTERISTICS FROM 3 APPROACHES*



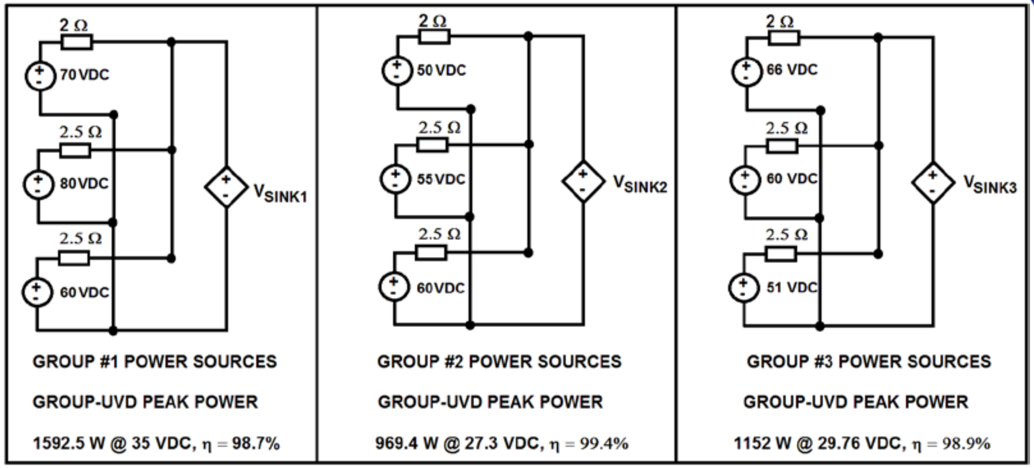

- <u>The best approach (IMPT) provides 842 W</u>
  → Nearly 100 % tracking efficiency out of ideal peak power (top curve with highest peak).

- The worst approach (GT-UCD) delivers only 88 % tracking efficiency.

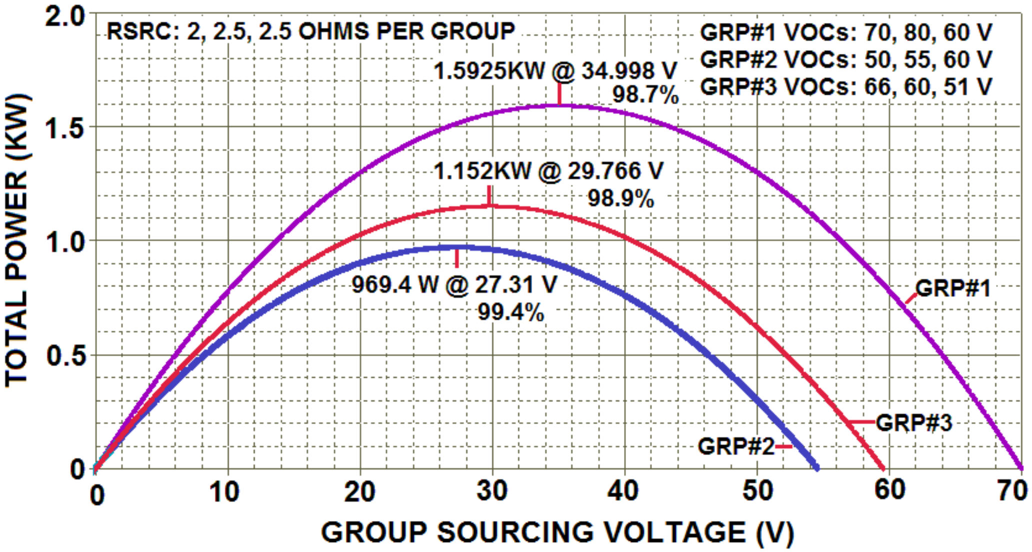
- <u>The optimized approach (GT-UVD) delivers 98.7 % tracking efficiency.</u>

# *GT-UVD for 3 Groups of Distributed Power Sources*

- Conceptual diagram for uniform input voltage distribution (UIVD),
- Power-versus-Voltage (P-V) characteristics for three power groups are analyzed and plotted from the diagram,
- GT-UVD for each of 3 power groups can be managed by using only one Group-Track MPT (GT-MPT) controller.




- **P-V DC characteristics per power group for three groups of power sources,**
- **Use of independent UIVD control for each group of distributed power sources,**
- **Achieving about 99% tracking efficiency in each power group.**




**2018 SPW**

# *Group-MPT with Uniform Time Division for Different Groups of Power Sources*

- **Group-MPT with Uniform Time Division (UTD-MPT)**
  - Equivalent to **IMPT** for each group of power sources (not for each power source)
  - Sharing only one common MPT controller
  - Actively performing an MPT control for one group of power sources at a time while holding the most recently tracked group peak-power voltages of the remaining groups of distributed power sources.

- **Distributed power sources and distributed-input series-output (DISO) converters are controlled for**
  - Achieving the group peak-power voltages across their respective sources,
  - Tracking the peak power voltage of each power source group sequentially and repetitively with equal time distribution,
  - Independent Uniform Input Voltage Distribution (UIVD) control for each group of power sources.

## *Group Maximum Power Tracking with Uniform Time Distribution among Different Groups of Power Sources*

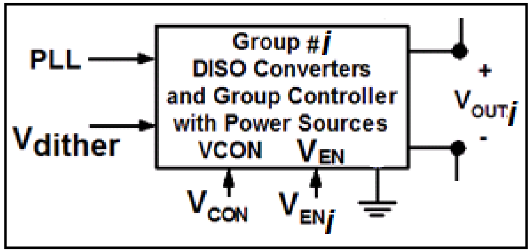
- The system peak power is the maximum power drawn from groups of the distributed power sources while UTD-MPT is active for tracking distributed group peak-power voltages.

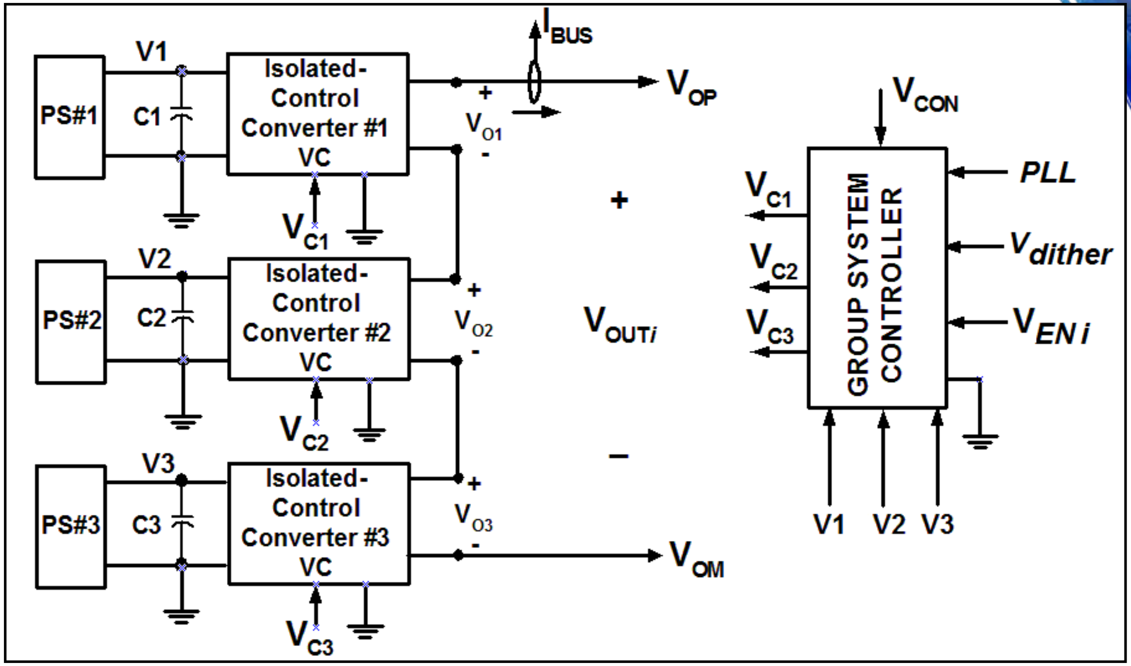
- With equal time distribution control, peak powers of all power sources are tracked by

  - Using only one non-linear controller for MPT

  - Eliminating distributed IMPT controllers, each of which is conventionally dedicated to one associated group of distributed power sources.

# DISO Converters per One Group of 3 Distributed Power Sources

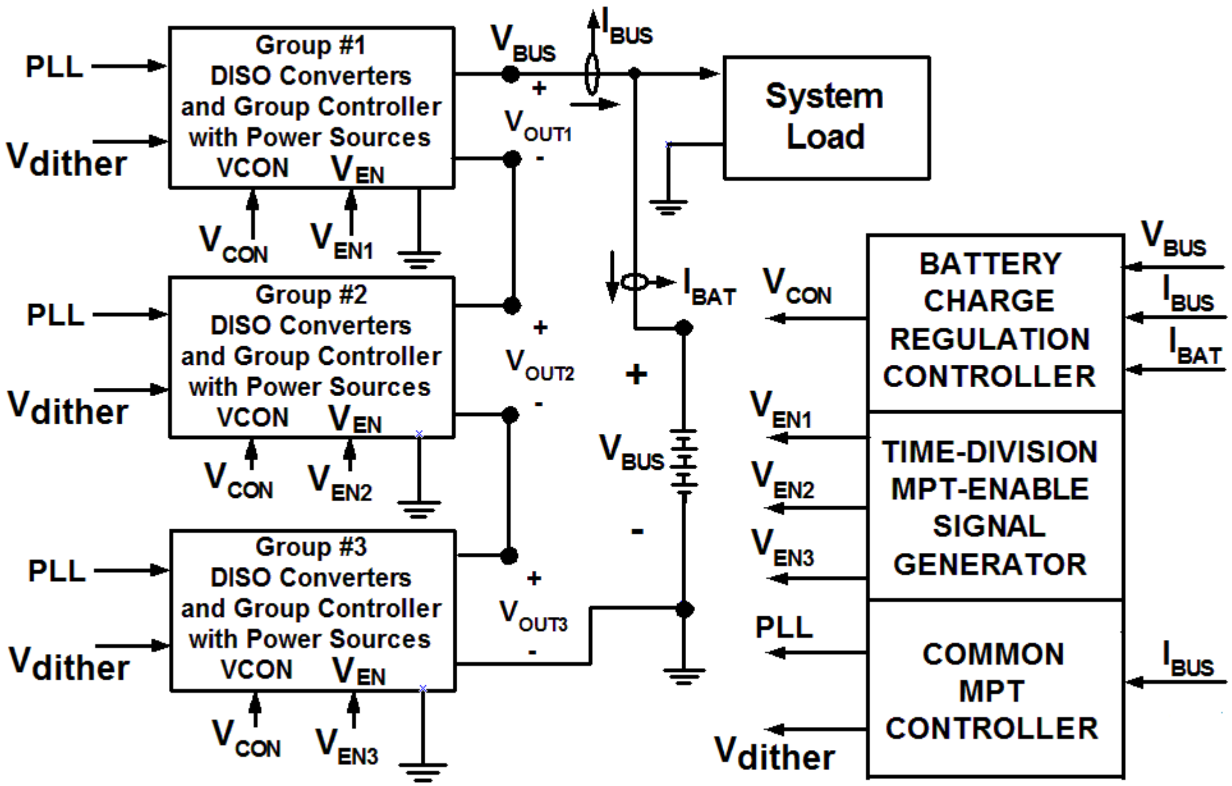



- Each group of DISO converters possesses a group system controller for obtaining Uniform Input Voltage Distribution (UIVD) among the distributed sourcing voltages.

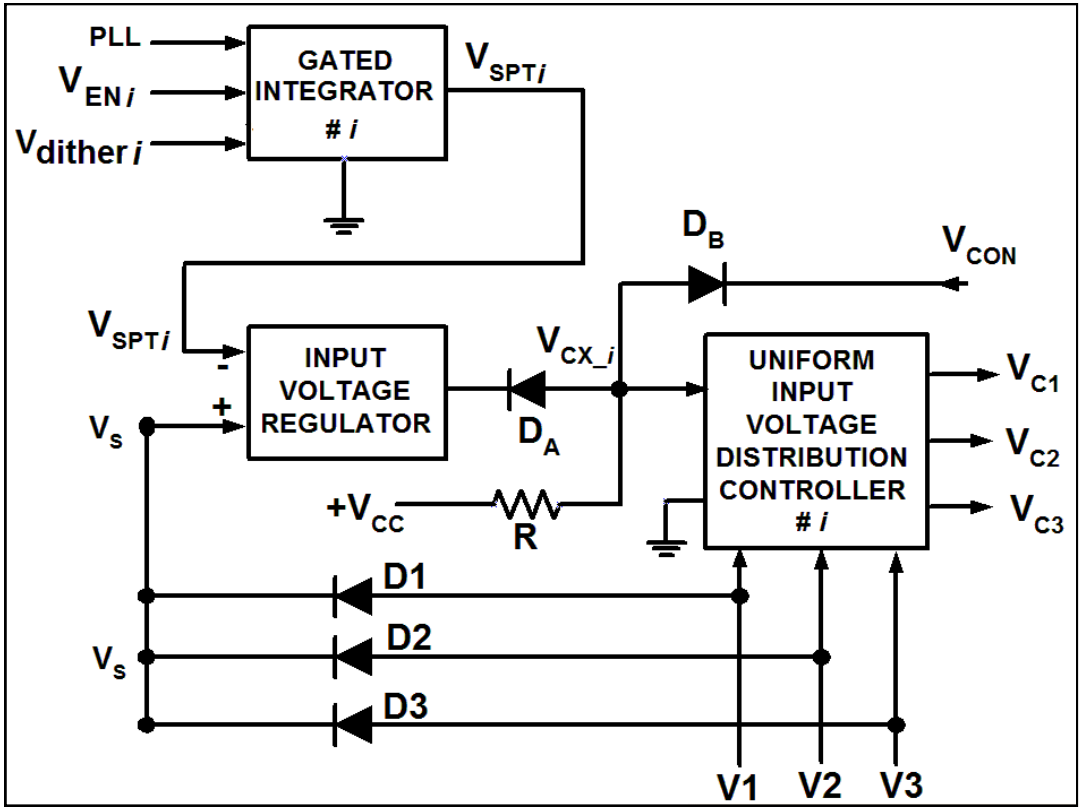
- 3 groups of power sources need three group system controllers, each of which provides UIVD among three associated input voltages, $V_1$, $V_2$, and $V_3$.

# *Battery-Dominated Power Architecture With UVD and UVD MPT Control*




- Group peak-power voltages, one per power source group, are actively controlled by the common MPT controller for one power source group at a time, while holding their most recently tracked group peak-power voltages of the remaining groups of power sources.

# *System Controller for Battery-Dominated Power Architecture With Uniform Time Distribution MPT*

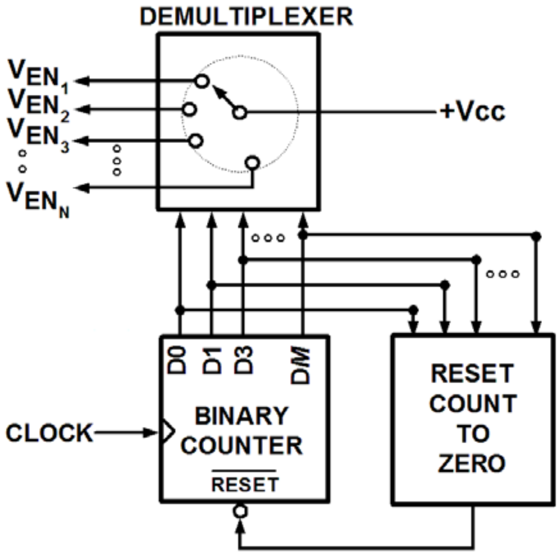


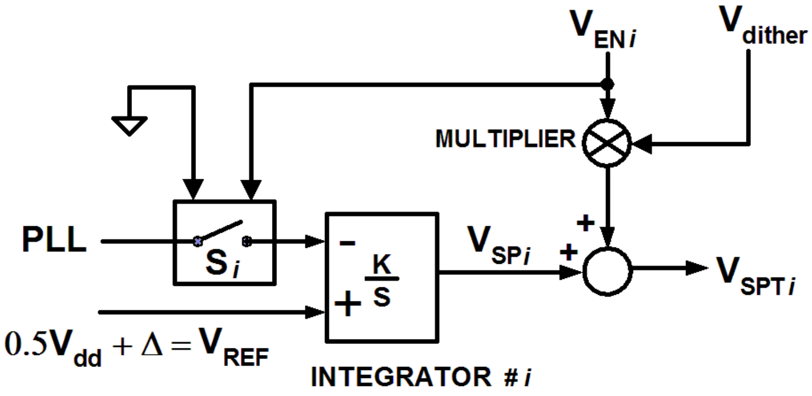

The highest value of distributed input voltages, $V_S$,

$$V_S = MAX(V_1, V_2, V_3)$$

is fed back and regulated at their group peak-power voltage, $V_{SPTi}$ .

# *Repetitive Address for the De-Multiplexer*



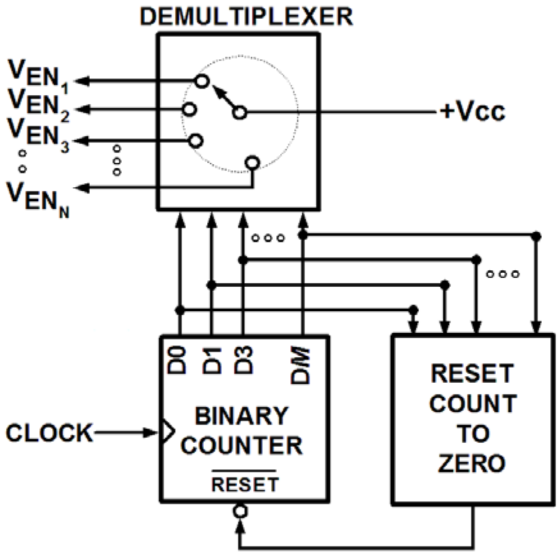



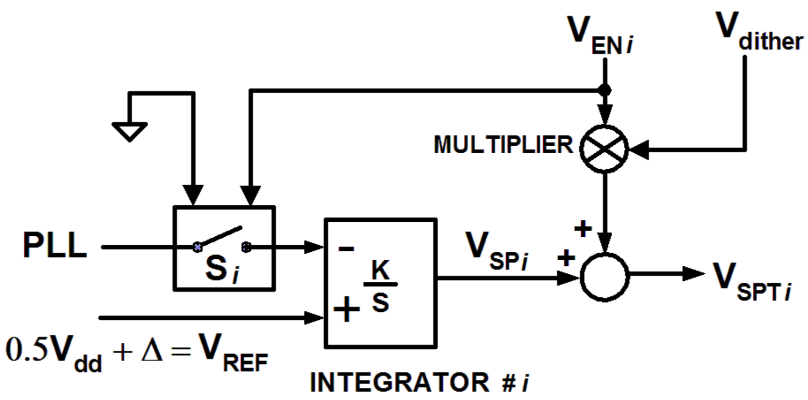

- Binary counter repetitively produces its N-address counting sequence into an M-bit address bus to feed the de-multiplexer that distributes group-enable signals, $V_{ENi}$, to their respective group integrators.

- Group peak-power set-point voltages, $V_{SP1}$, $V_{SP2}$ , and $V_{SP3}$, *are updated sequentially according to the sequentially active states of their group-enable signals* $V_{EN1}$, $V_{EN2}$ , and $V_{EN3}$.

- Note that N = number of DISO converter groups (in this study N = 3).

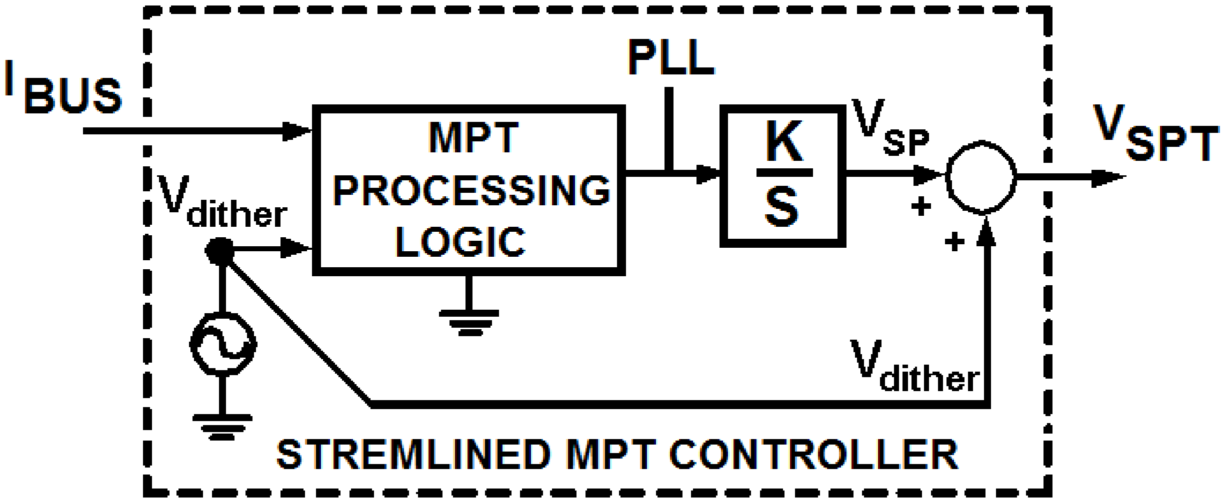
# *Repetitive Address for the De-Multiplexer*



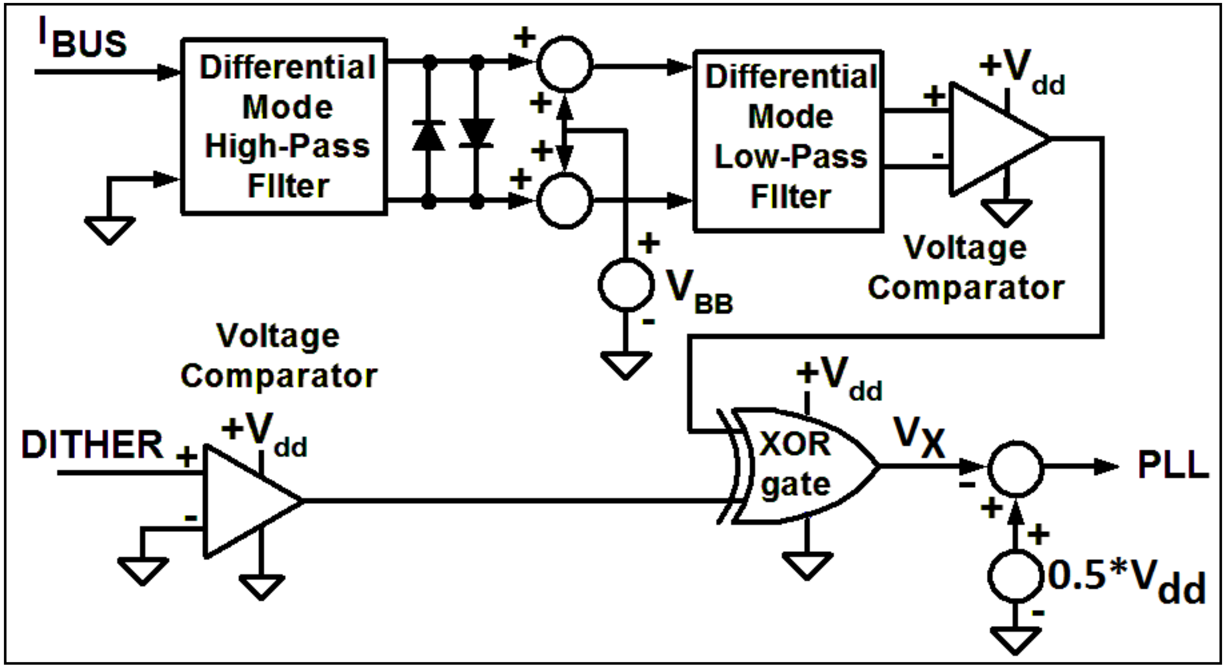

- One $V_{EN\boldsymbol{i}}$ *signal is active one at a time while the remaining* $V_{EN\boldsymbol{j}}$ *signals (**j** is not equal to **i**) are inactive,*
- *One active* $V_{ENi}$ *signal enables group #i's DISO converters for updating their group peak-power voltage.*
  - *3 groups used in this study*
  - $V_{EN1}$, $V_{EN2}$ , and $V_{EN3}$
- *Gated-Integrator # **i** is within group # **i** system controller, where **i** = 1, 2, and 3 in this study.*

# *Conceptual Diagram of Streamlined MPT Controller*



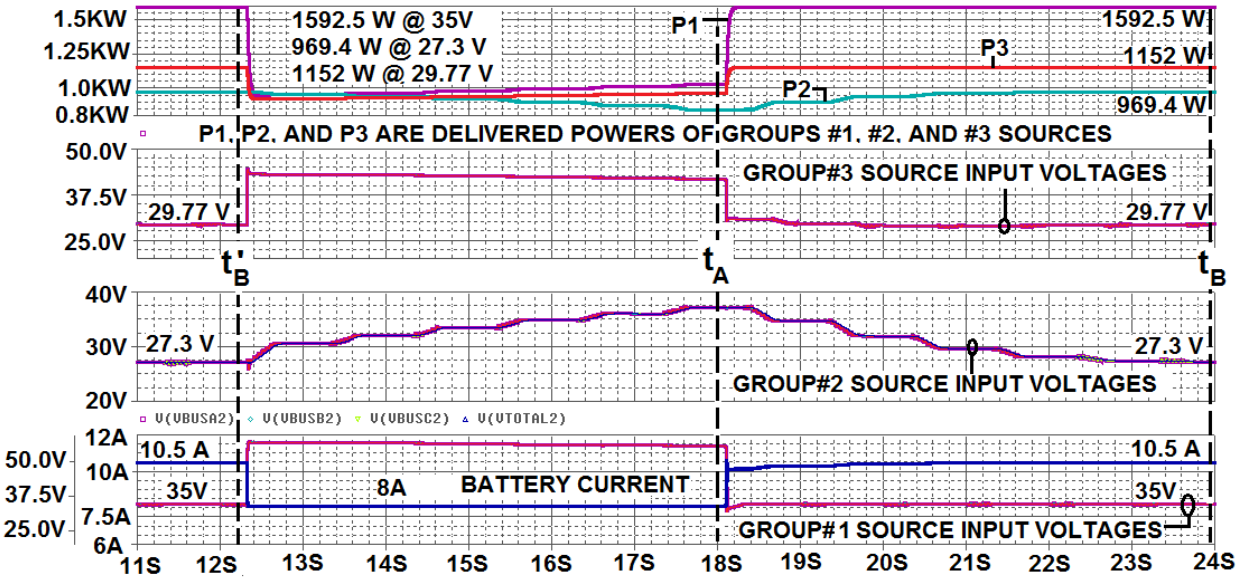

- Simpler MPT Controller uses only one feedback signal $I_{BUS}$ for production of the output signal $V_{SPT}$.
- $I_{BUS}$ equivalently represents the total power signal
- $V_{dither}$ provides reliable AC voltage, faithfully representing the phase of the array voltage ripple
- $V_{SPT}$ is the set-point voltage commanding signal
- $V_{SPT}$ represents the group peak-power voltage

# *Analog and Logic Processing Circuit within the Simplified MPT Controller*




- DITHER signal, which is available internally, eliminates the high-pass and low-pass filters since the AC signal is clean and serves as the much more reliable signal for the actual AC ripple of solar array voltage which most likely contains undesirable switching noise.

# *Simulation of the Battery-Dominated Power System*

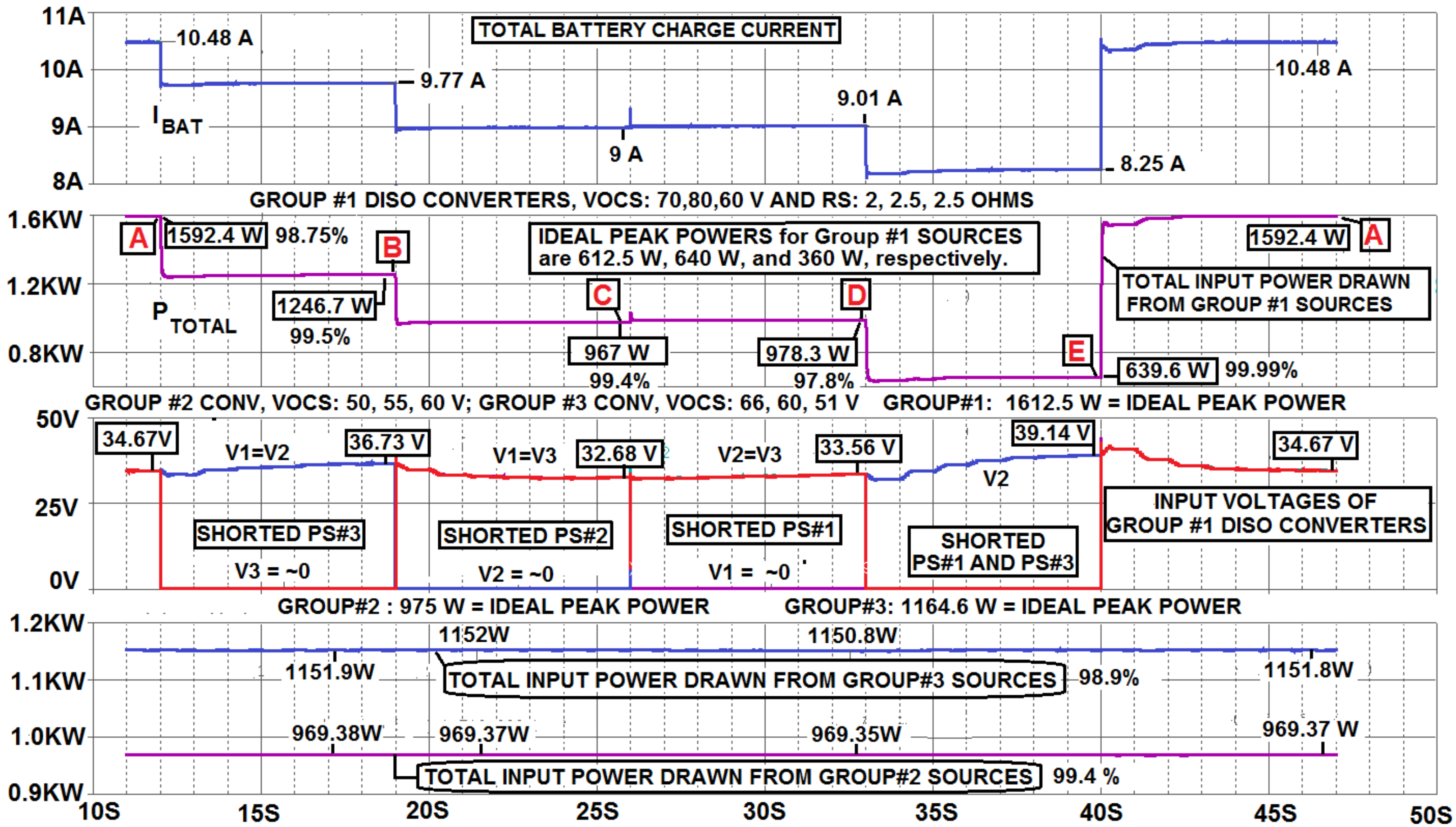



Transitions between Two Operational Modes (MPT and BCR):

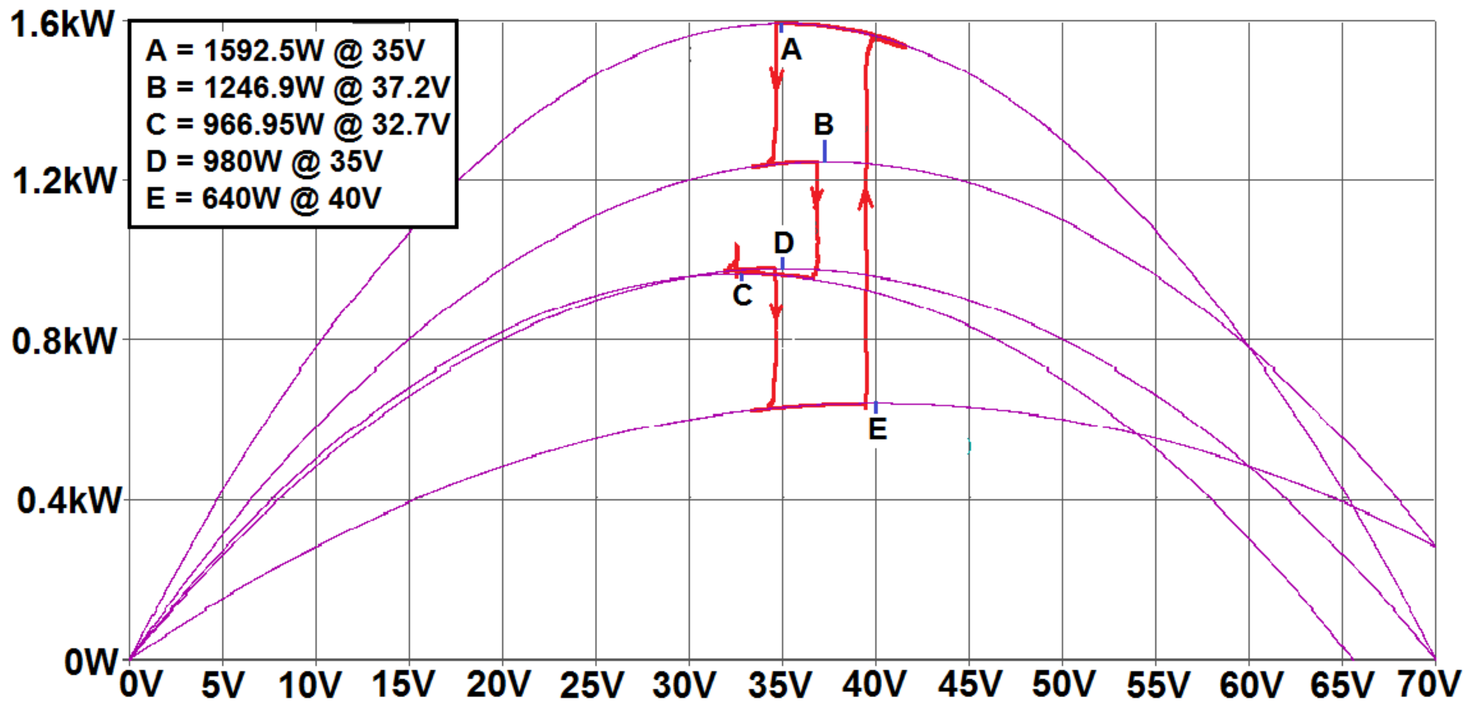
- In MPT mode, Input Voltage Regulation (IVR) controllers of three groups of DISO converters regulate their sourcing input voltages at their respective group peak power voltages such as those voltages at time $t_B$ (or $t_B'$)

- In Battery Current Regulation mode (BCR), the battery charge controller regulates the battery current to its commanding set-point (8 A) and the input source voltages of all groups are above their associated group peak-power voltages (not in MPT mode) such as those voltages at time $t_A$ .

# *Tolerance of Multiple Failures (up to N-1 Sources )*

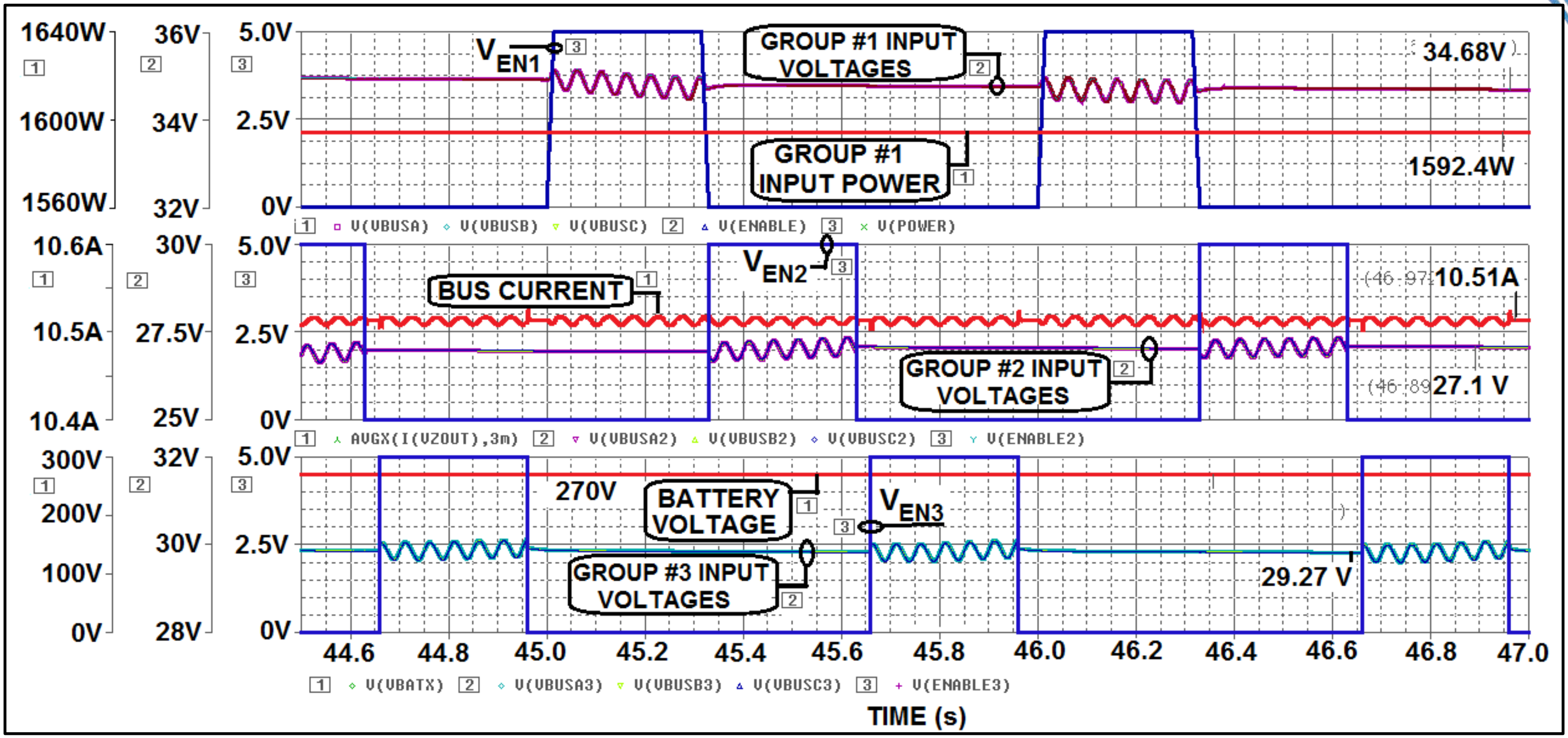



For any group of power sources, equal time-shared MPT can tolerate loss of more than one power source without loss of MPT function for the remaining functional sources.




- Anticipated response of Group #1 power sources, with a Time-Shared MPT controller & 3 respective DISO converters,
  - Revealing P-V trajectory transitions between two consecutive peak-power points (points A, B, C, D, and E, then back to A),
  - Depending on the number of active power sources (i. e. up to three power sources in power group #1) controlled by three DISO converters.

# *Uniform Time Distribution of MPT among 3 Groups of Power Sources*




Only one group of source voltages exhibits their voltage ripple at the dither frequency while the remaining groups of source voltages are held steady at their most recent peak power voltages.

# *Simulation of the Battery-Dominated Power System with 3 Groups of Distributed Power Sources and a common time-shared MPT Controller*

- PSPICE simulation verifies that UTD MPT control
  - Can continuously update new group peak-power points due to the changed characteristics of the distributed sources.
  - Is applicable when the MPT response time is negligible when compared to the time for each of the array sources to change its peak power voltage.
  - Is capable of tolerating more than one power source failures since the failed power sources do not cause undesirable consequences to the controller function.

# *CONCLUSION*

*Uniform time distribution of group maximum power tracking among different groups of distributed power sources has been validated through computer simulation for a battery-dominated bus power architecture.*

- *Only one MPT controller is shared in common to obtain a nearly-ideal peak power of the whole system with reduced component counts, resulting in ease of control design & troubleshooting with maximum fault-tolerance (N-1 fault-tolerances per power group),*
- *The single MPT controller can track group peak-power voltages for many groups of power sources having different DC characteristics.*
- *Uniform time distribution is feasible for slow changes in the source peak power voltages as compared to the MPT response time.*

# *APPENDIX B: MPT Controller*