# Closed-Ring Collector Equivalencing for BESS


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**Abstract- This note adapts the collector-system loss-equivalencing method of Muljadi et al. from radial wind-plant feeders to a closed-ring battery energy storage system collector with a single point of connection (PoC). Under the same simplifying assumptions of identical inverter current injections and approximately flat 1 pu bus voltage, explicit branch-current multipliers are derived for the ring and used to construct a single equivalent cable that preserves the total cable real and reactive losses at a selected operating point. The resulting expression retains the same weighted-loss structure as the Muljadi method, but replaces radial downstream current weights with loop-consistent ring-current weights.**



**Index Terms- battery energy storage system, collector system, equivalencing, aggregation, ring network, apparent-power loss.**


## I. Introduction

Muljadi et al. described a loss-based method for replacing a wind-plant collector system with an equivalent collector impedance chosen to preserve the apparent-power losses of the original network [1], [2]. In the original formulation, the collector is radial or daisy-chain, and the branch currents are obtained from cumulative downstream turbine injections. The same loss-preserving philosophy is attractive for grid-scale battery plants; however, many battery collector systems may be ringed rather than radial.

This note presents a topology-specific modification of the Muljadi method for a closed ring with one PoC, N identical inverter injections, unique cable sections, and a single full-load operating point. The objective is narrow but practical: replace the ring collector and the N individual inverters with one lumped inverter and one equivalent cable such that total cable P- and Q-consumption are unchanged at the selected operating point.

## II. Problem Statement and Assumptions

Let node 0 denote the PoC, and let nodes 1,...,N denote the inverter nodes. The cable sections are indexed sequentially around the ring as 0 -> 1 -> 2 -> ... -> N -> 0. Section k has series impedance

$$z_k = r_k + jx_k, \text{where } k = 1, \dots, N+1 \qquad (1)$$

and shunt susceptance $b_k$. The following assumptions are adopted, consistent with the collector-loss equivalencing philosophy of [1], [2]: 1) all inverters inject the same three-phase current phasor $I_{inv}$; 2) all bus voltages are approximated as 1 pu for collector reduction; 3) only fundamental-frequency steady-state cable losses are matched; and 4) only one operating point, typically full load, is considered.

The branch currents $I_k$ are defined positive in the same direction as the cable indexing. Because each inverter injects the same current, Kirchhoff's current law at the inverter nodes gives

$$I_{k+1} - I_k = I_{\text{inv}}, k = 1, \dots, N \qquad (2)$$

## III. Closed-Ring Modification of the Muljadi et al. Method

Equation (2) implies that the ring currents differ from one branch to the next by one inverter current. Accordingly, each branch current may be written as a common loop-closing term plus an open-ring current ramp:

$$I_k = I_{\text{circ}} + (k-1)I_{\text{inv}}, k = 1, \dots, N+1 \qquad (3)$$

Because the collector is closed, the net voltage drop around the loop must be zero. Under the flat-voltage assumption, Kirchhoff's voltage law gives

$$\sum_{k=1}^{N+1} z_k I_k = 0 \qquad (4)$$

Substituting (3) into (4) yields the circulating-current term

$$I_{\text{circ}} = -I_{\text{inv}} \frac{\sum_{k=1}^{N+1}(k-1)z_k}{\sum_{k=1}^{N+1} z_k} \qquad (5)$$

For compactness, define the ring constants

$$Z_\Sigma = \sum_{k=1}^{N+1} z_k \qquad (6)$$

$$Z_w = \sum_{k=1}^{N+1} (k-1) z_k \qquad (7)$$

so that

$$I_{\text{circ}} = -I_{\text{inv}} \frac{Z_w}{Z_\Sigma} \qquad (8)$$

and the current in branch k becomes

$$I_k = I_{\text{inv}}\left[(k-1) - \frac{Z_w}{Z_\Sigma}\right] \quad (9)$$

Define the dimensionless branch-current multiplier

$$\mu_k = (k-1) - \frac{Z_w}{Z_\Sigma} \quad (10)$$

Then

$$I_k = \mu_k I_{\text{inv}} \quad (11)$$

Equation (11) is the closed-ring analogue of the Muljadi feeder current weighting. In the radial case, the branch weights are downstream sums. In the present closed-ring case, they are loop-consistent current multipliers obtained from simultaneous KCL and KVL closure.

The complex loss in section k is

$$S_{\text{loss},k} = |I_k|^2 z_k \quad (12)$$

and the total complex loss of the original ring is

$$S_{\text{loss,ring}} = \sum_{k=1}^{N+1} |I_k|^2 z_k = |I_{\text{inv}}|^2 \sum_{k=1}^{N+1} |\mu_k|^2 z_k \quad (13)$$

When the N identical inverters are replaced by one lumped inverter, the equivalent inverter current is

$$I_{\text{eq}} = N I_{\text{inv}} \quad (14)$$

The equivalent series cable impedance $z_{eq}$ is chosen so that the lumped representation produces the same cable real and reactive losses as the original ring:

$$|I_{\text{eq}}|^2 z_{\text{eq}} = S_{\text{loss,ring}} \quad (15)$$

Substituting (13) and (14) into (15) gives the closed-form equivalent cable

$$z_{\text{eq}} = \frac{1}{N^2} \sum_{k=1}^{N+1} |\mu_k|^2 z_k \quad (16)$$

Hence

$$r_{\text{eq}} = \frac{1}{N^2} \sum_{k=1}^{N+1} |\mu_k|^2 r_k \quad (17)$$

$$x_{\text{eq}} = \frac{1}{N^2} \sum_{k=1}^{N+1} |\mu_k|^2 x_k \quad (18)$$

## IV. Shunt Capacitance and Special Cases

Following the same 1 pu bus-voltage assumption used in [1], [2], the cable shunt susceptances may be aggregated directly as

$$b_{\text{eq}} = \sum_{k=1}^{N+1} b_k \quad (19)$$

This shunt term should generally be retained separately from the equivalent series impedance. If each section is a different length of the same cable type, so that $z_k = l_k z_0$ with real length factor $l_k$, then $Z_w / Z_\Sigma$ is real and the branch-current multipliers $\mu_k$ are also real. In that case, the equivalent cable weights reduce to ordinary scalar squares rather than squared magnitudes.

## V. Discussion

The principal connection to Muljadi et al.'s original collector reduction is structural rather than notational. Both methods preserve collector apparent-power losses and both rely on identical current injections together with a 1 pu bus-voltage assumption. The distinction is that a radial feeder admits a simple cumulative downstream current count, whereas a ring requires one additional loop-closing correction shared by all branches. Once that common correction is known, the equivalent impedance again takes the familiar loss-weighted form.

The derivation here is intentionally restricted to cable aggregation for a single operating point. It does not attempt to preserve voltage drop, partial-load behavior, inverter controls, transformer losses, or harmonic-frequency effects. Practical experience with converter-based device modelling likewise indicates that reduced representations must be selected with care for the intended study objective [3]. Any aggregation necessarily destroys information; the engineer must take responsibility for the suitability of the aggregation applied and for any consequences arising from its use.

## VI. Conclusion

A closed-ring BESS collector can be reduced using the same loss-matching philosophy introduced by Muljadi et al. for radial wind-plant collectors, provided the radial branch-current weights are replaced by loop-consistent ring-current multipliers. Under identical inverter injection and flat-voltage assumptions, the resulting equivalent series cable is obtained in closed form from a weighted sum of the original cable impedances, while cable shunt susceptances are summed directly. The method is simple enough for hand checking, yet general for arbitrary ring section impedances.

## References


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