A Presentation on

A New Indicator for Bus Level Voltage Stability Monitoring of Stressed Power Systems

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Introduction

Voltage stability may be defined as the inability of power network to meet/ transmit the incremental reactive losses associated with incremental load.

The aspects of voltage stability studies

- Computation of exact distance to collapse
- Estimation of distance to collapse using some indicator
- Evaluation of methodologies to design control strategies to pursue voltage instability

This paper addresses the development of a new indicator to warn against the proximity of present operating state to instability

The aspects of voltage stability studies

- The voltage instability proximity indicators may be evaluated:

  - Using locally available information hence these are more suitable for local on-line applications
  - Using information available at central load dispatch facility

Mathematical modeling

The proposed method is based on the fact that at critical loading all the complex incremental power pushed towards a load node is lost in the lines as losses.

This means that the phasor representing incremental power supplied towards a load node overlaps over the total line losses.

This also means that the angle between these two phasor reduces to zero at critical loading.

Mathematical modeling

In this paper the proximity of cosine of angle between the phasor representing total incremental complex power pushed towards the load node and the total incremental complex power loss in the connected lines to unity is taken as proximity to voltage instability.

Mathematical modeling

These phasors can be quickly evaluated using local bus measurements and prior knowledge of line parameters.

Mathematical modeling

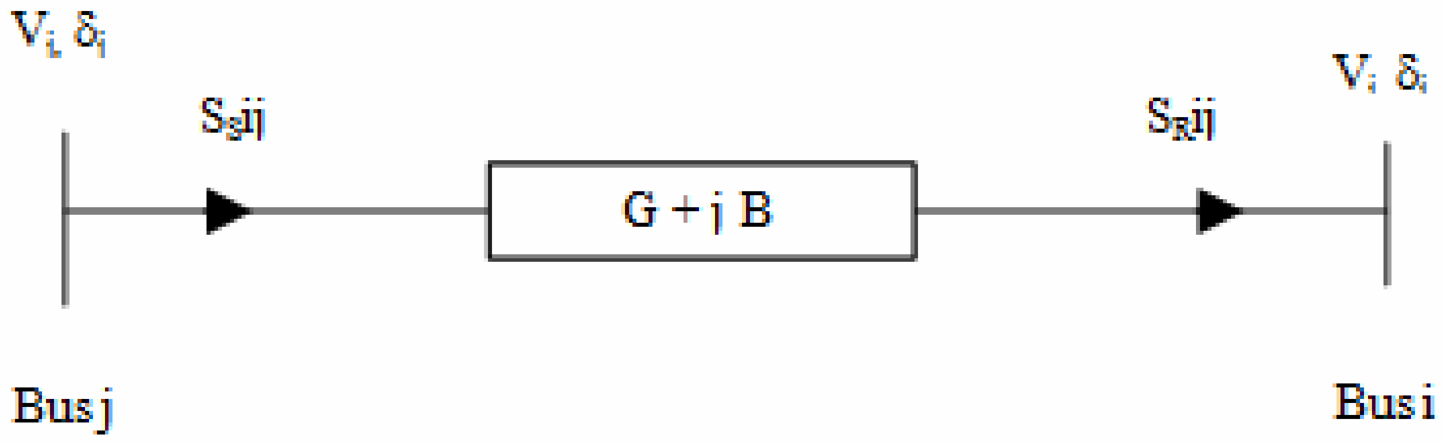

Figure 1: Complex power flow in the line connecting Bus i and Bus j

Mathematical modeling

$$\Delta P_{Rji} = -V_iV_j\{-G_{ij}Sin(\delta_i-\delta_j)+B_{ij}Cos(\delta_i-\delta_j)\}\Delta\delta_i$$
$$-V_iV_j\{G_{ij}Sin(\delta_i-\delta_j)-B_{ij}Cos(\delta_i-\delta_j)\}\Delta\delta_j \quad (5)$$
$$-[2G_{ii}V_i - V_j\{G_{ij}Cos(\delta_i-\delta_j\}+B_{ij}Sin(\delta_i-\delta_j)]\Delta V_i$$
$$-V_i\{G_{ij}Cos(\delta_i-\delta_j)+B_{ij}Sin(\delta_i-\delta_j)\}\Delta Vj$$

$$\Delta Q_{Rji} = -V_iV_j\{G_{ij}Cos(\delta_i-\delta_j)+B_{ij}Sin(\delta_i-\delta_j)\}\Delta\delta_i$$
$$-V_iV_j\{-G_{ij}Cos(\delta_i-\delta_j)-B_{ij}Sin(\delta_i-\delta_j)\}\Delta\delta_j \quad (6)$$
$$+[2B_{ii}V_i - V_j\{G_{ij}Sin(\delta_i-\delta_j)-B_{ij}Cos(\delta_i-\delta_j)\}]\Delta V_i$$
$$-V_i\{G_{ij}Sin(\delta_i-\delta_j)-B_{ij}Cos(\delta_i-\delta_j)\}\Delta V_j$$

Mathematical modeling

$$\begin{aligned}\Delta P_{Sji} = {} & V_j V_i \{ G_{ji} Sin(\delta_j - \delta_i) - B_{ji} Cos(\delta_j - \delta_i) \} \Delta \delta_j \\ & + V_i V_j \{ - G_{ji} Sin(\delta_j - \delta_i) + B_{ji} Cos(\delta_j - \delta_i) \} \Delta \delta_j \\ & + V_j \{ G_{ji} Cos(\delta_j - \delta_i) + B_{ji} Sin(\delta_j - \delta_i) \} \Delta V_i \\ & + [2 G_{jj} V_j + V_i \{ G_{ji} Cos(\delta_j - \delta_i) + B_{ji} Sin(\delta_j - \delta_i) \}] \Delta V_j \end{aligned} \tag{7}$$

$$\begin{aligned}\Delta Q_{Sji} = {} & V_j V_i \{ - G_{ji} Cos(\delta_j - \delta_i) - B_{ji} Sin(\delta_j - \delta_i) \} \Delta \delta_i \\ & + V_j V_i \{ G_{ji} Cos(\delta_j - \delta_i) + B_{ji} Sin(\delta_j - \delta_i) \} \Delta \delta_j \\ & + V_j \{ G_{ji} Sin(\delta_j - \delta_i) - B_{ji} Cos(\delta_j - \delta_i) \} \Delta V_i \\ & + [- 2 B_{jj} V_j + V_i \{ G_{ji} Sin(\delta_j - \delta_i) - B_{ji} Cos(\delta_j - \delta_i) \}] \Delta V_j \end{aligned} \tag{8}$$

Mathematical modeling

Let,

$\Delta \mathbf{S}_{\mathbf{Rji}} = \Delta P_{Rji} + j\,\Delta Q_{Rji}$

= Incremental complex power received at bus i end of the line connected between bus i and bus j.

$\Delta \mathbf{S}_{Sji} = \Delta P_{Sji} + j\,\Delta Q_{Sji}$

=Incremental complex power pushed at bus j end of the line connected between bus i and bus j.

The real and reactive losses in the line, ΔP_{Lossij} and ΔQ_{Lossij} can be calculated as follows,

$$\Delta P_{Lossji} = \Delta P_{Sji} - \Delta P_{rji} \qquad (9)$$

$$\Delta Q_{Lossji} = \Delta Q_{Sji} - \Delta Q_{Rji}$$

$\Delta \mathbf{S}_{Lossji} = \Delta P_{Lossji} + j\,\Delta Q_{Lossji}$

= Incremental complex power loss of the line connected between bus i and bus j.

Mathematical modeling

Now, let us generalize the case for multiple lines being terminated into bus 'i'.
Total complex power pushed towards bus i

$$= \sum_{\substack{j=1 \\ j \neq i}}^{n} \Delta S_{Sji}$$

Similarly, total complex power loss of all the lines connected to bus i

$$= \sum_{\substack{j=1 \\ j \neq i}}^{n} \Delta S_{Lossji}$$

At critical loading; total incremental complex power pushed from the sending ends of all the connected lines gets entirely consumed in meeting the losses of lines resulting in the net received incremental power equals to zero, i.e.

$$\sum_{\substack{j=1 \\ j \neq i}}^{n} \Delta S_{Rji} = 0 \qquad (11)$$

Or

$$\sum_{\substack{j=1 \\ j \neq i}}^{n} \Delta S_{Lossji} = \sum_{\substack{j=1 \\ j \neq i}}^{n} \Delta S_{Sji} \qquad (12)$$

Results

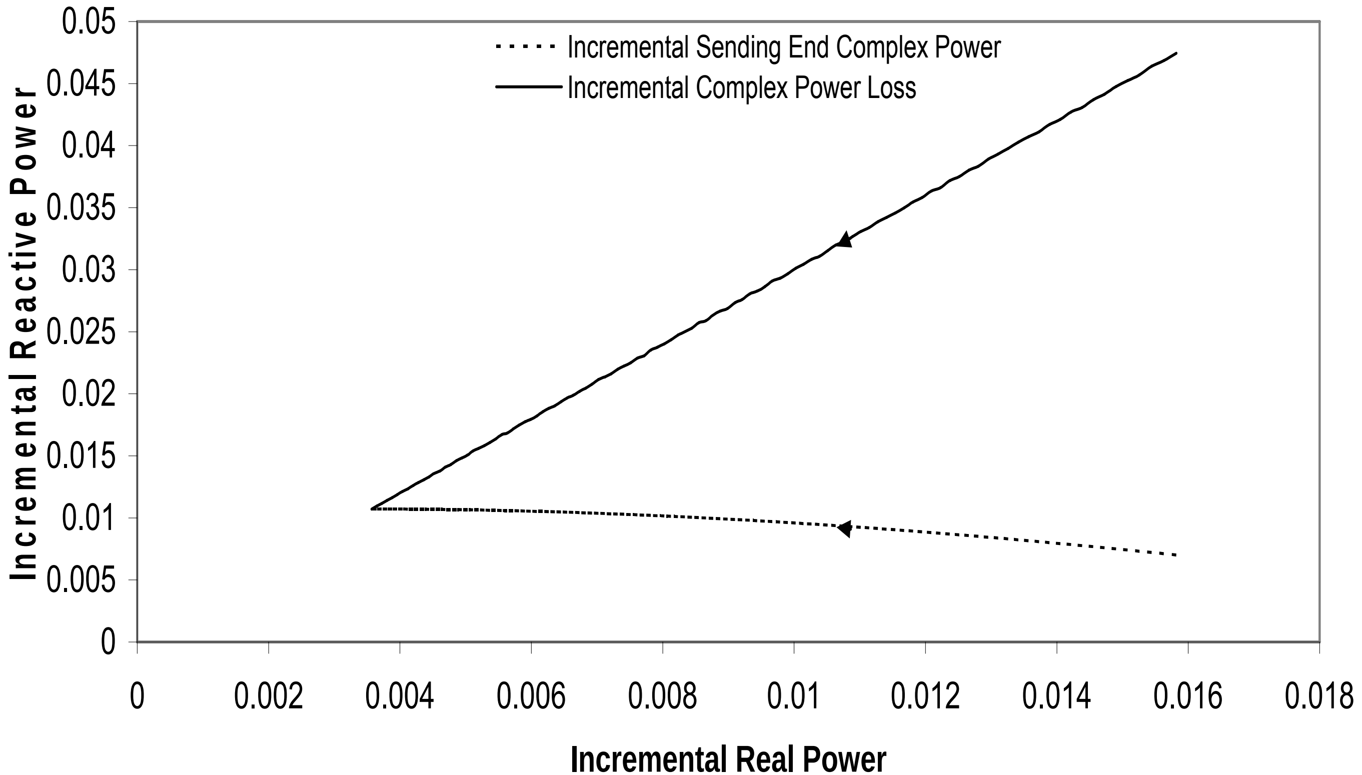

Figure 2(a): Loci of ΔS_S and ΔS_{Loss} in sample two bus system as loading parameter varies from zero(Base case loading) to critical value with proportionate increase in load

Results

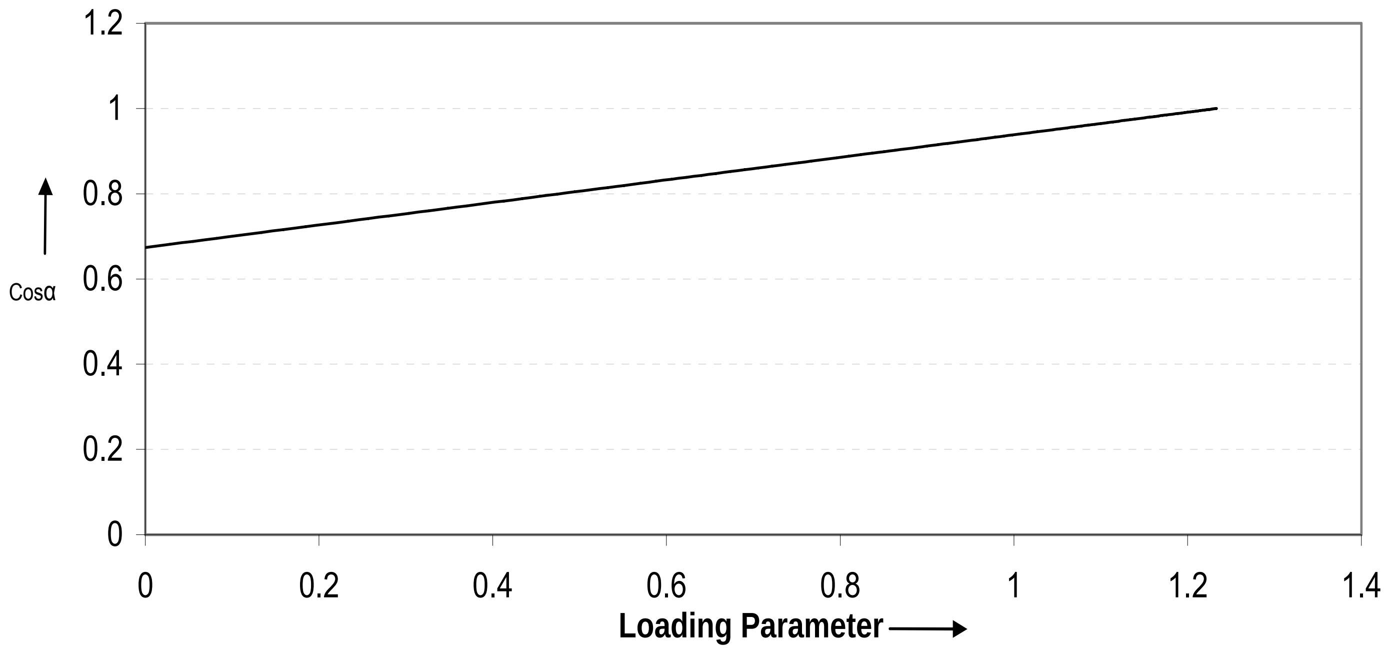

Figure 2(b) : Variation in Cosα with Loading parameter for sample two bus system when system load is increased uniformly from the base case load

Results

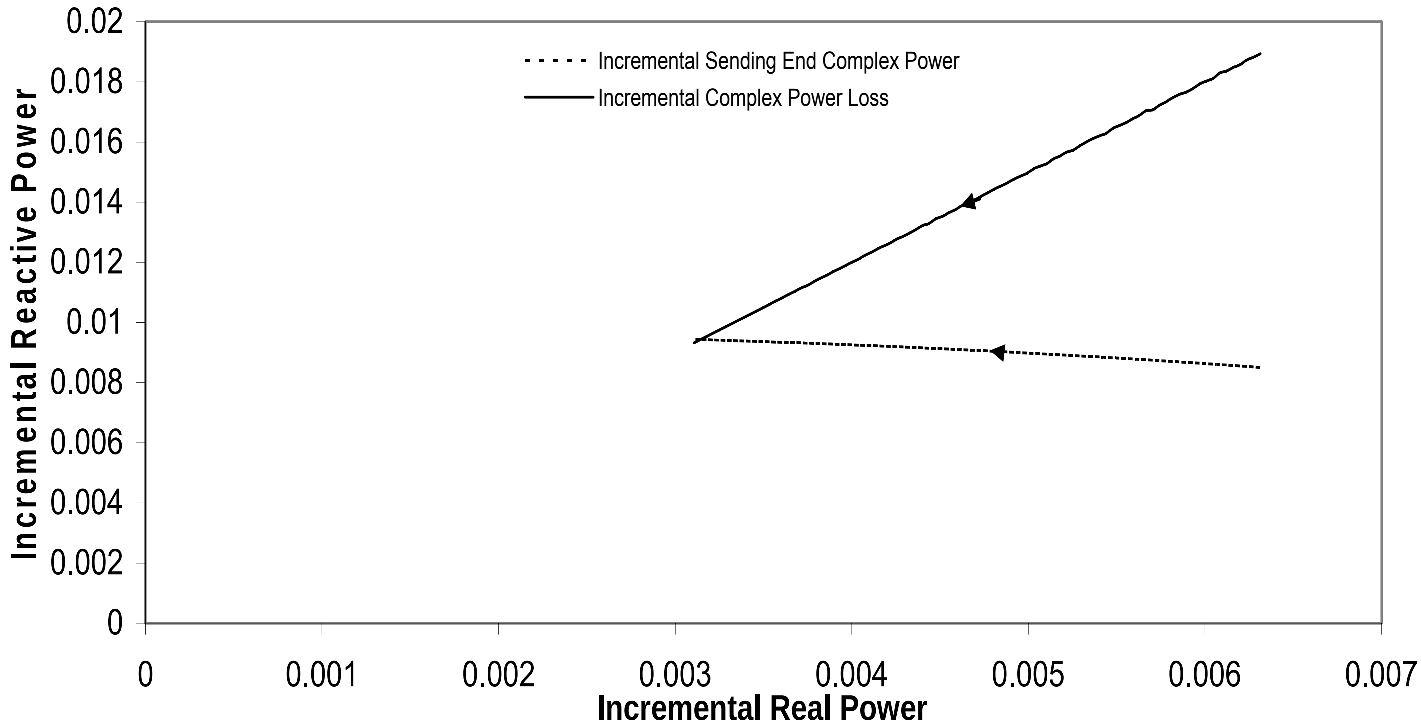

Figure 3(a): Loci of ΔS_S and ΔS_{Loss} in sample two bus system as loading parameter varies from zero (base case loading) to critical loading with increase in load at 0.8 power factor

Results

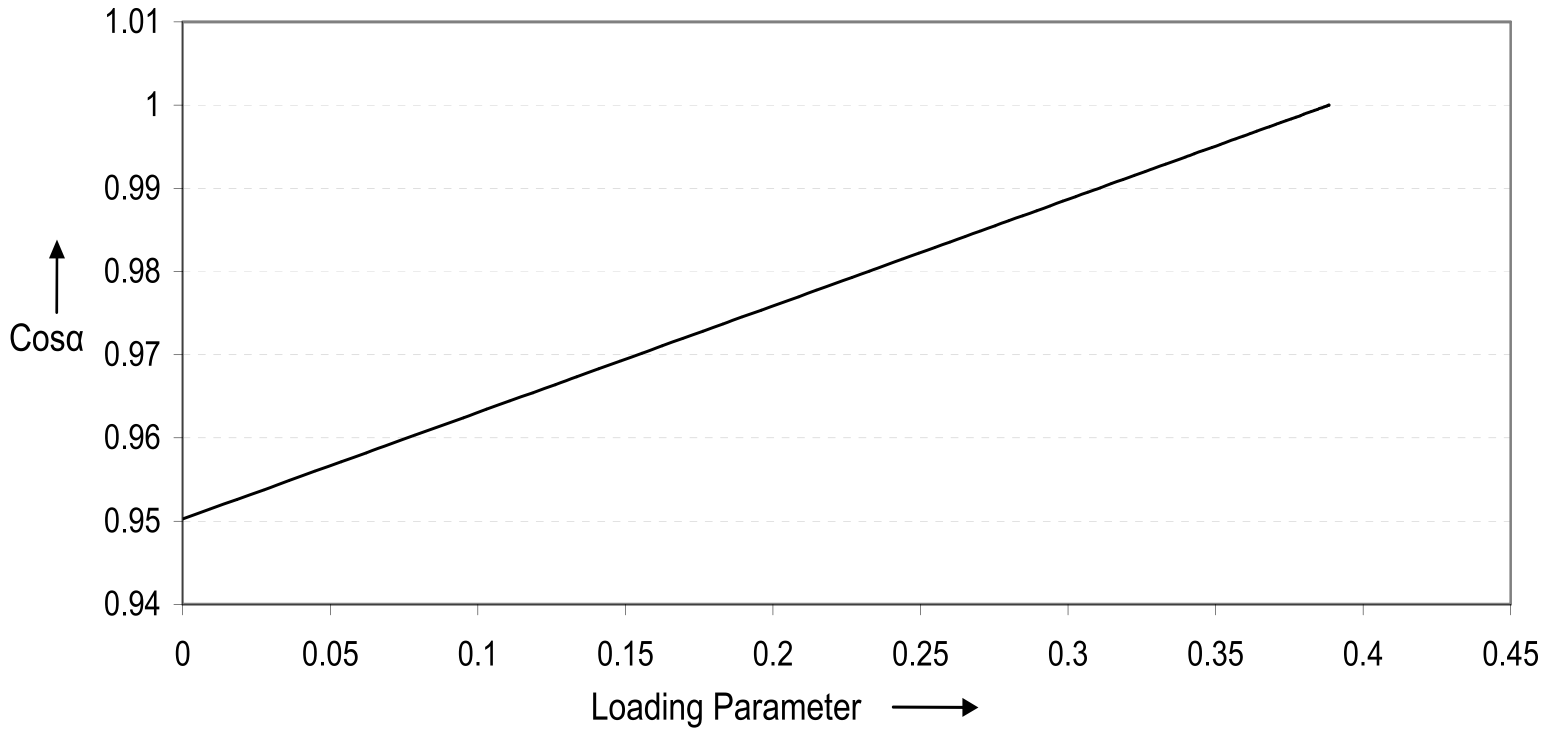

Figure 3(b):Variation in Cosα with loading parameter as load at bus I is increased at 0.8 power factor lagging in sample two bus system

Results

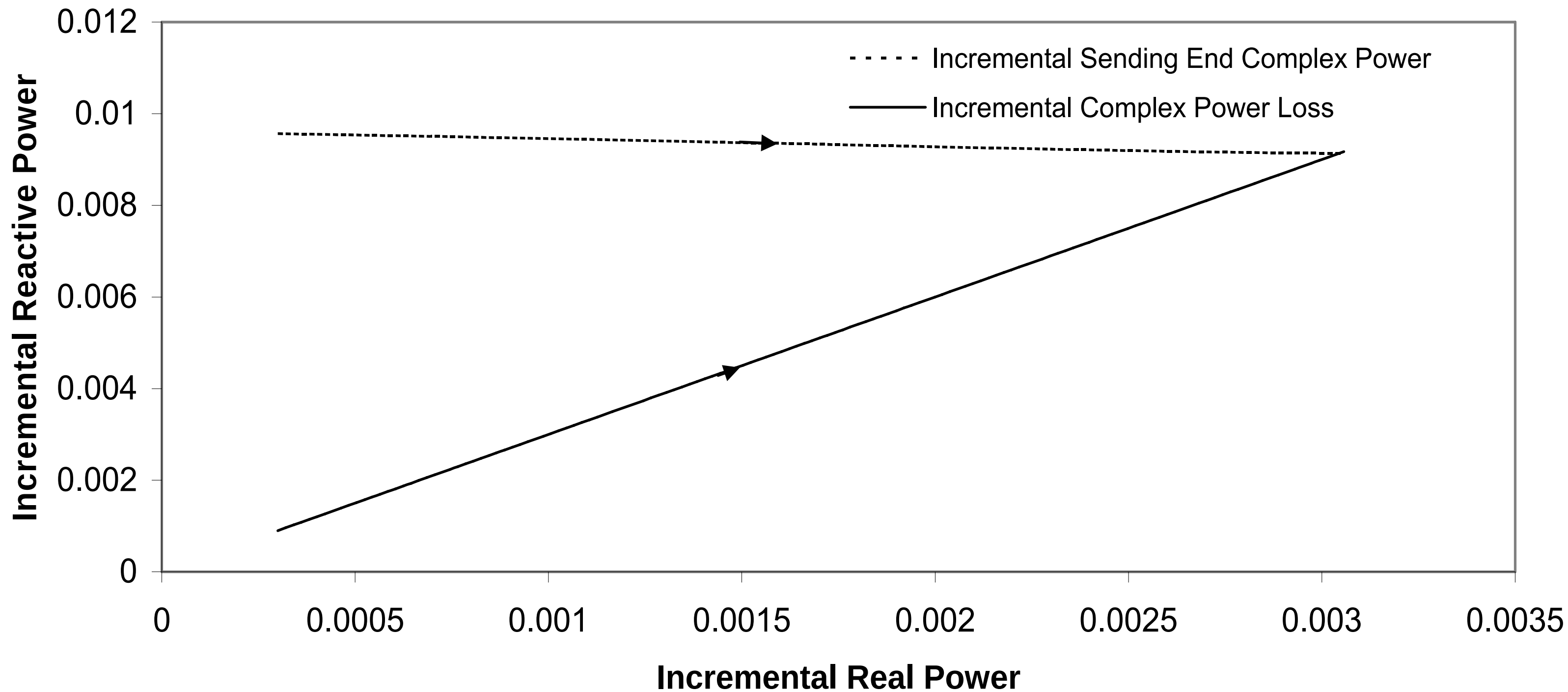

Figure 4(a): Loci of ΔS_S and ΔS_{Loss} in the incremental power plane as loading parameter varies from zero(base case loading) to critical loading at zero power factor for sample two

Results

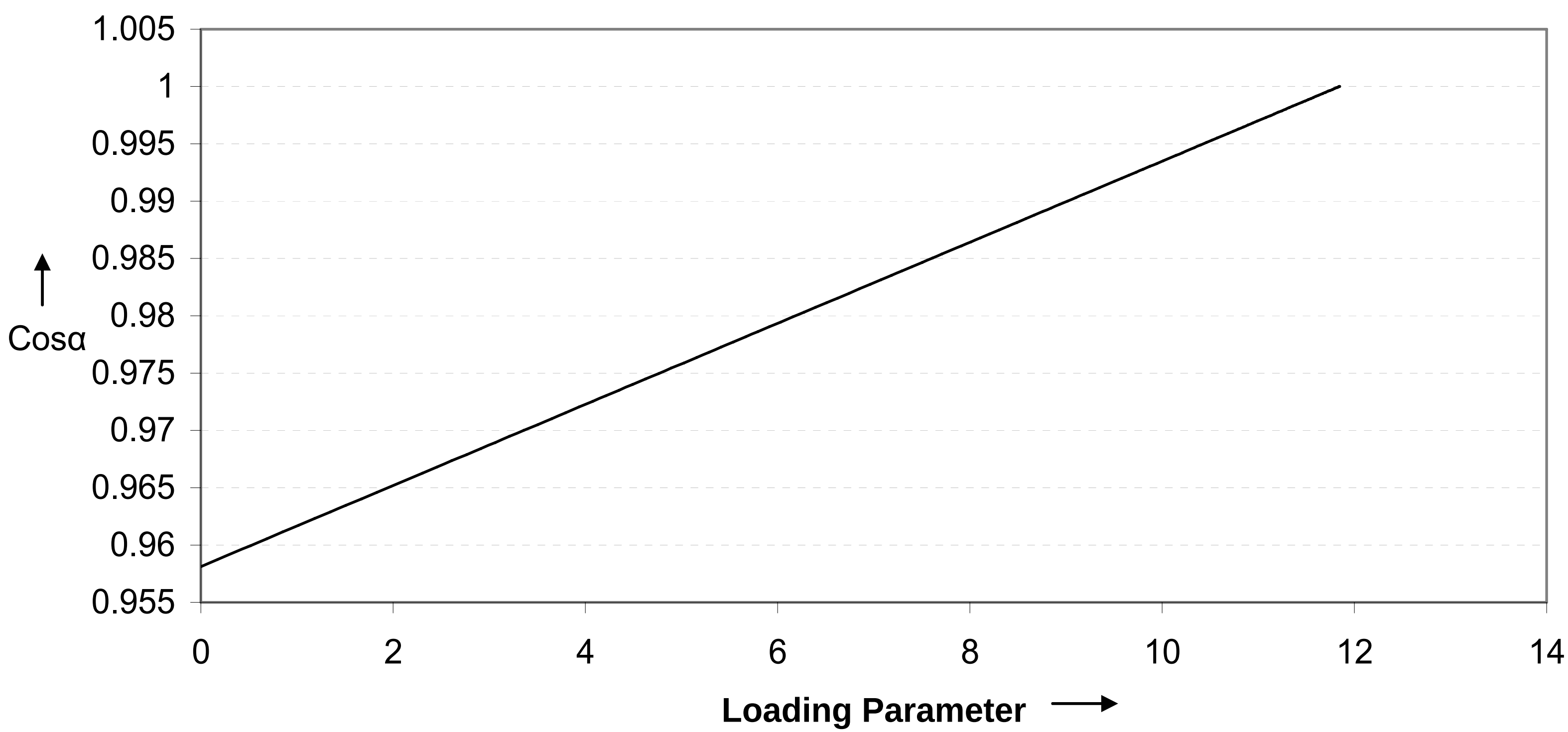

Figure 4(b): Variation in Cosα with loading parameter in sample two bus system when the load is increased at zero power factor lagging from base case load

Results

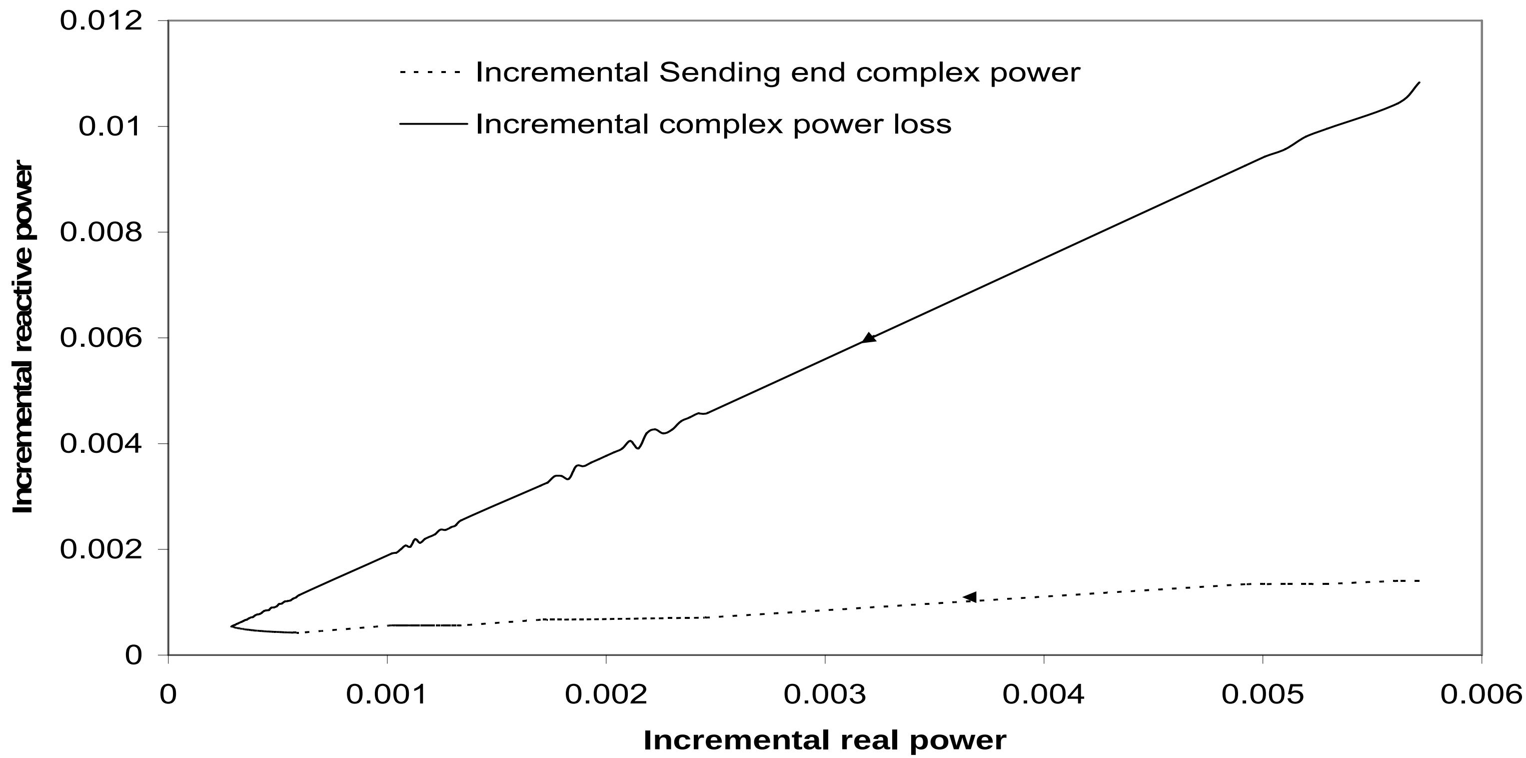

Figure 5(a): Loci of ΔS_S and ΔS_{Loss} at bus 30 of IEEE 30 bus test system as the system loading is increased proportionately from base case loading(λ=0) to critical loading

Results

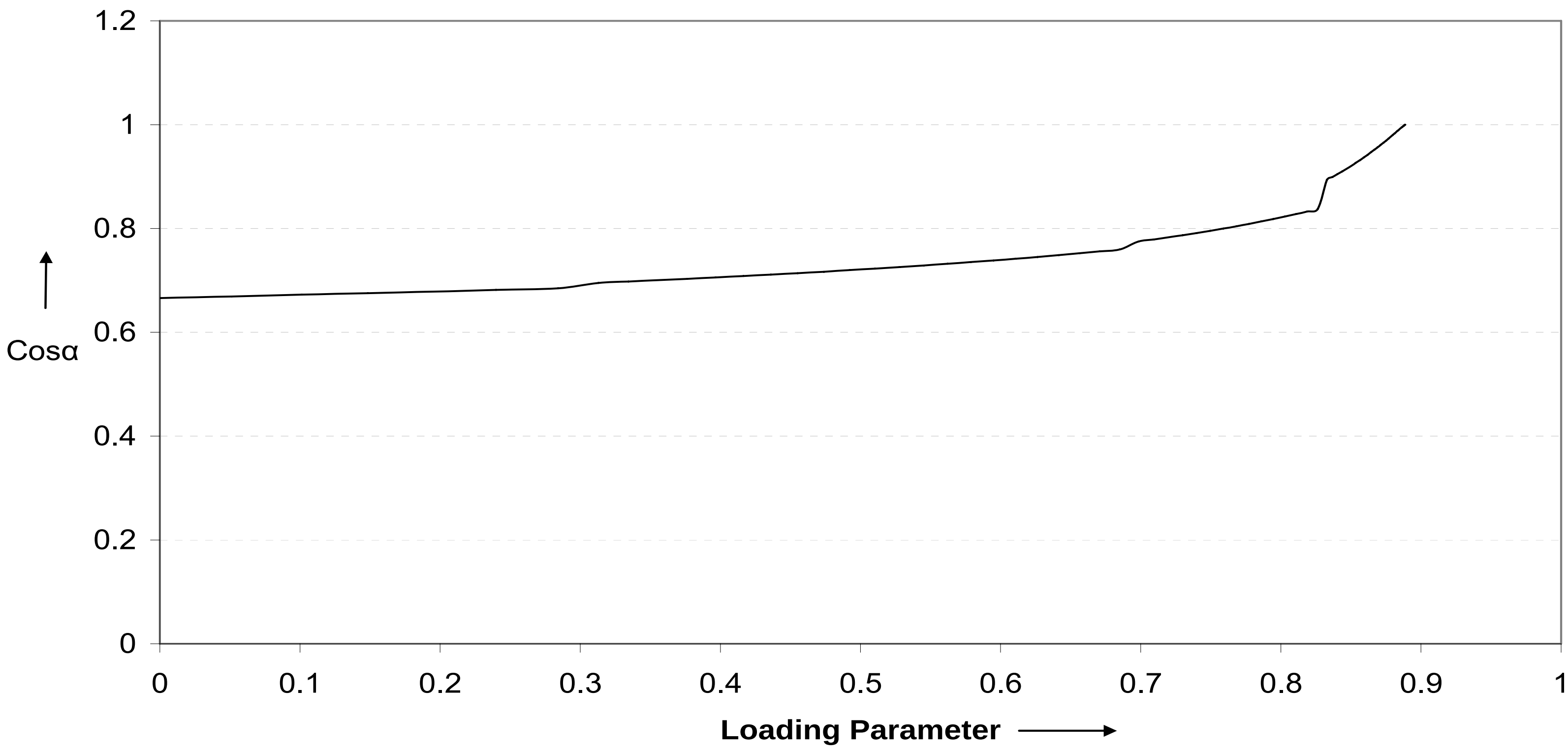

Figure 5(b):Variation in Cosα at bus 30 for IEEE 30 bus test system with loading parameter λ

Conclusions

A new indicator for monitoring power system state against voltage instability has been proposed based on the incremental sending end complex powers and complex incremental losses of all the lines feeding the load bus under observation. This indicator exhibits better performance under various load increase patterns and reactive limit violations at generators as compared to earlier proposed VIPIs based on incremental powers. It can be evaluated at bus level. The proposed algorithm can be implemented in numerical relay for protection of power system against voltage instability.

Thanks & Quires are Welcome