Agron BISLIMI

ORCID: 0000-0002-7368-7216

DOI: 10.15199/48.2025.05.48

Comparative evaluation of initialization methods for continuation power flow in power system stability

Ocena porównawcza metod inicjalizacji dla kontynuacji przepływu mocy w stabilności systemu elektroenergetycznego

***Abstract**. This paper presents a comparative evaluation of three initiation methods for the Continuation Power Flow (CPF) procedure in power system stability analysis. The first method uses conventional load flow calculations to determine initial node voltages, providing a stable starting point for CPF iterations. The second method bypasses the load flow step, initiating CPF directly with a load factor of λ = 0.3, which may result in slower convergence due to less accurate voltage estimates. The third method integrates external load flow programs to generate initial values, introducing variability in convergence depending on the accuracy of the external tool. Practical case studies demonstrate the efficiency, convergence characteristics, and trade-offs of each method. The analysis offers insights into the strengths and limitations of each approach, helping optimize CPF applications for stability studies. The findings aim to enhance grid stability analysis, supporting more informed decision-making in power system operation and planning.*

***Streszczenie.** W niniejszym artykule przedstawiono porównawczą ocenę trzech metod inicjacji dla procedury Continuation Power Flow (CPF) w analizie stabilności systemu elektroenergetycznego. Pierwsza metoda wykorzystuje konwencjonalne obliczenia przepływu obciążenia w celu określenia początkowych napięć węzłów, zapewniając stabilny punkt początkowy dla iteracji CPF. Druga metoda omija etap przepływu obciążenia, inicjując CPF bezpośrednio ze współczynnikiem obciążenia λ = 0,3, co może skutkować wolniejszą konwergencją z powodu mniej dokładnych szacunków napięcia. Trzecia metoda integruje zewnętrzne programy przepływu obciążenia w celu wygenerowania wartości początkowych, wprowadzając zmienność konwergencji w zależności od dokładności zewnętrznego narzędzia. Praktyczne studia przypadków demonstrują wydajność, cechy konwergencji i kompromisy każdej metody. Analiza oferuje wgląd w mocne i słabe strony każdego podejścia, pomagając zoptymalizować zastosowania CPF w badaniach stabilności. Wyniki mają na celu ulepszenie analizy stabilności sieci, wspierając bardziej świadome podejmowanie decyzji w zakresie eksploatacji i planowania systemu elektroenergetycznego.*

Keywords: Continuation power flow, power system stability, convergence analysis, load flow calculation, external load flow program
Słowa kluczowe: Kontynuacja przepływu mocy, analiza przepływu obciążenia, analiza zbieżności, stabilność systemu elektroenergetycznego, zewnętrzny program przepływu obciążenia

Introduction

The Continuation Power Flow (CPF**)** procedure is a crucial tool in power system analysis, particularly for assessing system stability under varying load and generation conditions. Unlike conventional load flow methods, CPF extends beyond a single operating point, enabling the tracing of voltage stability limits and loadability margins. The effectiveness of CPF analysis depends significantly on the method used to initiate the process, influencing factors such as convergence, efficiency, and accuracy.

This study evaluates and compares three initiation methods for CPF. The first method utilizes conventional load flow results for initial conditions, the second applies a direct load factor-based starting point, and the third integrates external load flow tools for initial estimates. Practical examples illustrate the convergence characteristics, trade-offs, and computational efficiency of each method, offering valuable insights for optimizing CPF applications in power system stability studies.

The primary objective of this study is to assess these methods in order to enhance CPF implementation and improve power system stability analysis.

Sources [2, 3] provide comprehensive explanations of the CPF method, emphasizing its role in steady-state voltage stability analysis. They highlight how CPF optimizes iteration convergence, identifies stability limits, and improves the accuracy of power system assessments.

In references [4-8], the CPF method, iteration convergence, and its application within the trigonometric circle are explored. These studies examine voltage stability through the tangent slope during CPF iterations, along with a detailed analysis of critical factors influencing power system behavior and performance, including Load Factor (λ), Power Balance, Active Load Variation, and Increment Factors (τ).

In reference [4], the study focuses on enhancing iteration convergence within the CPF method to improve the accuracy of voltage stability assessments. By identifying indicators of convergence and divergence, this research seeks to optimize computational efficiency and resource utilization while increasing the precision of voltage stability analyses.

In reference [5], a novel methodology is proposed for determining PV curves via tangents, which are utilized as stability indicators for voltage. The study further examines the relationship between the slope of tangent vector components during CPF iterations, contributing additional stability insights.

Reference [6] offers a comprehensive analysis of key factors that influence the behavior of modern power systems, such as Load Factor (λ), Power Balance, Active Load Variation, and Increment Factors (τ). The paper aims to optimize the reliability and operational efficiency of power systems through an in-depth understanding of these factors.

In reference [7], an optimized voltage stability analysis approach is presented, integrating elements from the admittance matrix that are precomputed to enhance both the efficiency and reliability of the analysis process.

Paper [8] introduces an innovative CPF analysis method utilizing the Trigonometric Circle to visualize power system behavior. This method facilitates the identification of critical points, such as voltage stability limits, and improves understanding of system dynamics. The study also emphasizes voltage stability analysis and CPFM compensation strategies to enhance overall system performance

Further studies [9-11] expand on voltage stability and power system analysis, providing deeper insights into the challenges and solutions for maintaining stability in modern power systems. Reference [12] investigates the issues with the logical PV/PQ switching method in Power Flow (PF) and CPF, revealing potential inaccuracies in load margin calculations. The study proposes two smooth function models for Q-V curves, improving both convergence and accuracy in load margin determination.

Reference [13] utilizes CPF to analyze voltage stability by progressively increasing load demand and tracking corresponding power flow solutions until stability limits are reached. The study incorporates the Unified Power Flow Controller (UPFC) in CPF analysis, highlighting the role of Flexible AC Transmission Systems (FACTS) in improving voltage stability. Article [14] reviews various CPF methods, comparing linear and nonlinear predictors, and explores correction steps using arclength parameterization to enhance prediction accuracy and system stability.

In [15], CPF is employed to assess static voltage stability limits, showing enhanced accuracy in systems with high renewable energy penetration, improving node voltage support with rising proportion coefficients.

Reference [16] examines the lifetime distribution functions of critical power system components, such as 20 kV poles, cables, and overhead-line sections, using optimal fitting techniques. These functions contribute to evaluating system reliability and informing maintenance strategies.

Article [17] analyzes multiple faults in aging networks using conditional probability and proposes restoration algorithms for cable and overhead-line systems, improving system reliability and supporting CPF initialization optimization for power system stability.

Paper [18] evaluates iterative linear methods for solving power flow problems, focusing on the Bi-conjugate Gradient Stabilized (BiCGStab) method for efficiently solving large systems. These methods are applicable to improving CPF initialization and stability assessments.

Voltage stability remains a critical issue in power systems, particularly during generation-demand mismatches. Effective reactive power compensation or load shedding is crucial to prevent instability and increase system capacity, as discussed in [19]. This concept aligns with CPF initialization optimization, offering valuable insights for enhancing voltage stability assessments and system reliability.

Reference [20] proposes fast second-order load flow calculations, significantly improving the efficiency of power system analysis, and is highly relevant to CPF initialization methods discussed in this study.

The structure of the paper is as follows:

The **Methods** section describes the approaches for initiating the Continuation Power Flow (CPF) procedure. It discusses conventional load flow calculations as a starting point, the direct initiation of CPF without prior load flow, and the use of external load flow programs for determining initial values.

The **Results** section provides a comprehensive comparative analysis, presenting detailed findings for each possibility.

Finally, the paper concludes with the **Conclusions** section, summarizing the key insights and implications of the study.

Methods: Possibilities for Initiating the CPF Procedure

CPF is an advanced technique used to analyze power systems beyond the limits of conventional load flow analysis. Unlike traditional methods that encounter convergence issues due to the singularity of the Jacobian matrix at the voltage stability limit, CPF modifies load flow equations to manage both stable and unstable regions of the PV curve.

CPF employs an iterative approach involving predictor and corrector steps. Network loads are incremented by a predefined percentage of the base load, guided by a parameter, λ (Lambda). In the predictor step, a tangent vector is computed to assess stability. When the system approaches instability, the node with the highest voltage magnitude in the tangent vector is selected as the new continuation parameter. The corrector step refines the solution to maintain this parameter, prevent voltage collapse, and ensure convergence.

This section outlines three approaches for initiating the CPF procedure, each with distinct implications for convergence and performance:

Possibility 1 - Conventional Load Flow Start

Input Values: Set $\lambda = 0$ (initial values for generation and load), assuming initial voltage magnitudes (e.g., 1.0) and voltage angles (e.g., 0.0).

Procedure: Perform a conventional load flow calculation using these initial values to compute node voltages.

CPF Initialization: Begin CPF by incrementing loads and, optionally, generation with a load factor of $\lambda = 0.3$. Use the computed initial voltage values to determine the elements of the augmented Jacobian matrix Jaug.

Iterations: Perform the predictor step using a step size factor of $\tau = 0.3$, following the equation: it1p=ito+τ·t

Then, execute the corrector step. The first CPF iteration is complete once convergence is achieved [1].

Possibility 2 - Direct CPF Start

Input Values: Set initial voltage magnitudes and voltage angles, similar to the conventional load flow method.

Procedure: Directly initiate the CPF procedure without performing a preliminary conventional load flow calculation. Increment loads and, optionally, generation using a load factor of $\lambda = 0.3$.

Jacobians and Tangent Vector: Compute the augmented Jacobian matrix Jaug and the tangent vector t.

Iterations: Execute the first predictor step with a step size of $\tau = 0.3$, followed by the corrector step. Compared to the conventional load flow approach in Section 2.1, the initial corrector iteration generally converges more slowly [1].

Possibility 3 - External Load Flow Program Start Procedure:

In contrast to Possibility 1, this approach utilizes an external load flow program for the initial load flow calculation.

Load Increase: Increase loads and, where applicable, generation, using a load factor of λ=0.3.

Initial Values: Use the voltage values derived from the external load flow program to compute the Jacobian matrix Jaug and determine the tangent vector t.

Iterations: Perform the predictor and corrector steps with a step size factor of τ=0.3. This method introduces variability in convergence, depending on the accuracy of the external tool used for the load flow calculation.

The three methods for initiating CPF - conventional load flow, direct CPF start, and external load flow program start - each offer distinct advantages for stability analysis. The first method starts with a conventional load flow calculation, the second directly initiates CPF, bypassing load flow, and the third uses an external load flow program to derive the initial values for CPF. Each approach has its trade-offs in terms of convergence speed and performance, providing various options depending on the specific needs of the analysis [1], [20].

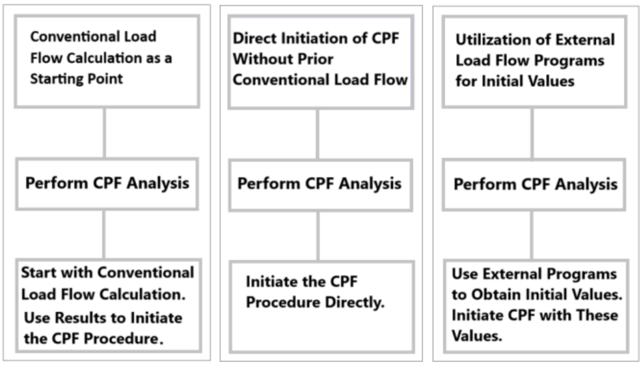

Fig.1. Different Possibilities for Initiating the CPF Procedure

This figure illustrates three distinct approaches to initiating the CPF procedure:

1. **Conventional Load Flow Start**: Perform a conventional load flow calculation to provide initial values for the CPF process.
2. **Direct CPF Start**: Initiate CPF directly, bypassing the conventional load flow calculation.
3. **External Load Flow Program Start**: Use an external load flow program to obtain initial values for CPF, instead of relying on an internally implemented load flow algorithm.

Each approach offers unique advantages and trade-offs, suited to different scenarios in power system stability analysis.

Results and Discussion:

The comparative analysis of the three possibilities for initiating the CPF procedure yielded the following findings:

Possibility 1: Conventional Load Flow Initialization

This approach utilizes initial values obtained from a conventional load flow calculation, providing a solid foundation for the CPF procedure. The method demonstrated reliable convergence across various load and generation scenarios, ensuring stability and consistency throughout the iterative process.

By using conventional load flow results as the starting point, both the predictor and corrector steps in the CPF were executed efficiently, leading to faster convergence and accurate solutions, particularly in the early CPF iterations. The approach effectively handled varying load factors, maintaining stability even under challenging conditions.

Overall, this initialization method proved to be a practical and dependable choice for CPF applications, offering both efficiency and robust performance. It is particularly suitable for scenarios where accurate initial conditions are crucial for achieving reliable results.

Data for the 2-Bus Network:

K=1.0; Po=0.1; ksi=0; Y_{21}= -10; Y_{22} =10; V_2=1.00; δ_2=0.000; θ_{21} =-1.5708; θ_{22} =-1.5708; Qo=0; ito= [0.00; 1.000; 0];

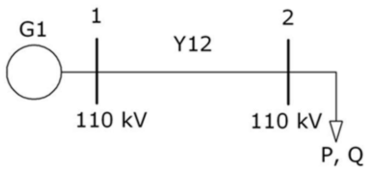

Fig. 2. Node Network

<u>Predictor step</u>:

Using the input data and the following equations, the elements of the Jacobian matrix **Jaug** are calculated:

$$\frac{\partial f1}{\partial \delta 2} = V2 * Y21 * \sin(\theta\, 21 - \delta 2\ )$$

$$\frac{\partial f1}{\partial V2} = Y21 * \cos\,(\theta\, 21 - \delta 2\ ) + 2 * Y22 * V2 * \cos\,(\theta 22)$$

$$\frac{\partial f2}{\partial \delta 2} = Y21 * V2 * \cos(\theta\, 21 - \delta 2\ )$$

$$\frac{\partial f2}{\partial V2} = -\,Y21 * \sin\,(\theta\, 21 - \delta 2\ ) - 2 * V2 * Y22 * \sin\,(\theta\ 22)$$

$$\text{Jaug} = \begin{vmatrix} [10.0000 & -3.6732 \times 10 - 5 & 0.1 \\ 3.6732 \times 10 - 5 & 10.0000 & 0 \\ 0, & 0 & 1 \end{vmatrix}$$

The tangent vector component t is given by:

t=inv (Jaug)*[0;0;1] t = [-0.0100, 0.0000,1.0000] ^{T}
T- transpose

For τ =0.0;

$$it1p = ito + \tau * t = [0,\ 1,\ 0]^T$$

Corrector step:

For the initial values δ2=0, V_2=1.0, and λ=0.000, the Jacobian matrix excluding **ek** vector and **λ** vector is

$$\text{Jo} = \begin{vmatrix} 10.0000 & -3.6732e-05 \\ 3.6732e-05 & 10.0000 \end{vmatrix}$$

The DFP (differential power flow) equations are:

$$Dfp = Po\,(1+K*\lambda) + V_2*Y_{21}*\cos\,(\delta_2 - \theta_{21}) + V_2{}^2*Y_{22}*\cos\,(\theta_{22})$$

$$Dfq = Po\,(1+K*\lambda) + V_2*Y_{21}*\sin\,(\delta_2 - \theta_{21}) + V_2{}^2*Y_{22}*\sin\,(\theta_{22})$$

The change in the solution is:

Ddk =-inv (Jo)*[Dfp; Dfq]

Resulting in:

$$\text{Ddk} = \begin{vmatrix} -0.0100 \\ 0.0000 \end{vmatrix}$$

Thus, the updated values are

$$\delta_3 = \delta_2 + D\delta_2 = 0.0000 + (-0.010) = -0.0100$$
$$V_2 = V_2 + DV_2 = 1.000 + 0.0000 = 1.00$$

For the values obtained after the first correction step, the voltage angle is δ2= −0.0100, and the voltage magnitude is V_2=1.000. The second correction step is then performed with these values.

The correction steps are repeated until Ddk is less than 0.0005 or approaches zero. This condition is met after the second correction step. The final values after the second correction step are:

δ_2= -0.010; V_2=1.0; λ=0.0000

Similarly, for these values, the second iteration is performed with λ = 0.3. After completing the second iteration, the following results are obtained:

δ_2= -0.0130; V_2=0.9999; λ =0.3000

Thus, the correction process converges after two iterations

Possibility 2: Direct CPF Initialization

Directly initiating CPF, without a prior conventional load flow calculation, typically led to slower convergence in the initial iterations. The absence of accurate initial voltage values hindered the efficiency of the predictor and corrector steps, resulting in additional iterations to achieve convergence and stability.

This approach proved less efficient than Possibility 1, particularly under high load factors, requiring more iterations to achieve similar accuracy and stability. Although it simplifies the setup by eliminating the need for an initial load flow calculation, it sacrifices convergence speed and stability.

Direct CPF initialization may be suitable when rapid implementation is prioritized over precision. However, its slower convergence and reduced stability in early iterations limit its effectiveness for scenarios requiring high accuracy and stability in CPF results.

Data for the 2-Bus Network:

K=1.0; Po=0.1; ksi=0; Y_{21}= -10; Y_{22} =10; V_2=1.00; δ_2=0.000; θ_{21} =-1.5708; θ_{22} =-1.5708; Qo=0; ito= [0.00; 1.000; 0];

Predictor Step:

The elements of the Jacobian matrix (Jaug) are calculated using the input data as follows:

$$\partial f1/\partial \delta 2 = V_2 * Y_{21} * \sin(\theta_{21} - \delta_2)$$
$$\partial f1/\partial V2 = Y_{21} * \cos(\theta_{21} - \delta_2) + 2 * Y_{22} * V_2 * \cos(\theta_{22})$$
$$\partial f2/\partial \delta 2 = Y_{21} * V2 * \cos(\theta 21 - \delta 2)$$
$$\partial f2/\partial V2 = -Y_{21} * \sin(\theta_{21} - \delta_2) - 2 * V_2 * Y_{22} * \sin(\theta_{22})$$

Jacobian Matrix (Jaug):

$$\mathrm{Jaug} = \begin{vmatrix} [10.0000 & -3.6732 \times 10-5 & 0.1 \\ 3.6732 \times 10-5 & 10.0000 & 0 \\ 0, & 0 & 1 \end{vmatrix}$$

$$\mathrm{t} = \mathrm{inv}\ (\mathrm{Jaug}) * \begin{vmatrix} 0 \\ 0 \\ 1 \end{vmatrix} = \begin{vmatrix} -0.0100 \\ 0.0000 \\ 1.0000 \end{vmatrix}$$

For τ =0.3;

it1p=ito + τ*t = [-0.0030, 1.0000, 0.3000]^T

Corrector Step: δ_2=-0.0030; V_2=1.0000; λ= 0.3000;

The Jacobian matrix excluding ek and λ vector is:

$$\mathrm{Jo} = \begin{vmatrix} 10.0000 & -3.6732e-05 \\ 3.6732e-05 & 10.0000 \end{vmatrix}$$

The differential power flow equations (Dfp and Dfq) are given by:

$$Dfp=Po\ (1+K*\lambda) + V_2*Y_{21}*\cos(\delta_2 - \theta_{21}) + V_2^{\,2}*Y_{22}*\cos(\theta_{22})$$

$$Dfq=Po\ (1+K*\lambda) + V_2*Y_{21}*\sin(\delta_2 - \theta_{21}) + V_2^{\,2}*Y_{22}*\sin(\theta_{22})$$

Ddk is calculated as:

$$\mathrm{Ddk} = -\mathrm{inv}\ (\mathrm{Jo}) * \begin{vmatrix} \mathrm{Dfp} \\ \mathrm{Dfq} \end{vmatrix}$$

For the first correction step, we obtain:

$\delta_3 = \delta_2$ + D δ_2 =-0.0030 +(-0.0100) =-0.0130
V_2= V_2+ DV_2=1.0000 +(-0.0000) =1.0000

Second Correction Step:

Using the updated values, the second correction step is performed. The process continues until Ddk < 0.0005, which is achieved after the third correction step. The final values after the t**hird correction step** are:

δ2 = -0.0130; V2 = 0.9999; λ = 0.3000;

Possibility 3: External Load Flow Program Start

This approach utilizes initial values obtained from an external load flow program, rather than using an internally implemented load flow algorithm. The procedure is as follows:

Values calculated with the external load flow program:

1. **First Iteration:**
   After the first iteration (λ = 0.3), the following values are obtained:
   δ2 = 0.013, V2 = 1.0, λ = 0.3000.
   These results are then used to calculate the matrix elements and proceed with the next iteration

The power calculation for λ = 0.3: K=1; Po=0.1, λ=0.3

→ P=Po (1+K λ) = 0.1*(1+ 1*0.3) =0.13*100 =13 MW

The values calculated using the **external program (Lastflussprogram)** are as follows:

Name of the Load Flow Dataset? **2kn-1.dat**

It: 1 It2: 1 Weight: 1.0000 Res.Sum.: 0.01690 Res.Sum.a: 1000000000000000000000.00000
It2: 1 Weight: 1.0000 Res.Sum.: 0.01690 Res.Sum.a: 1000000000000000000000.00000 Max.Res.: 0.13000 Node.KNOTEN2

It: 2 It2: 2 Weight: 1.0000 Res.Sum.: 0.00000 Res.Sum.a: 0.01690
It2: 2 Weight: 1.0000 Res.Sum.: 0.00000 Res.Sum.a: 0.01690 Max.Res.: 0.00169 Node.KNOTEN2

It: 3 It2: 3 Weight: 1.0000 Res.Sum.: 0.00000 Res.Sum.a: 0.00000
It2: 3 Weight: 1.0000 Res.Sum.: 0.00000 Res.Sum.a: 0.00000 Max.Res.: 0.00000 Node.KNOTEN2
Program End
Total Time: 0.08333min, Time Without Input: 0.00000min
Exit Program: Enter 0 to exit

Table 1. Load Flow Dataset Name: 2kn-1.dat

Iteration	1	2	3
Iteration Step	1	2	3
Weight	1.0000	1.0000	1.0000
Residual Sum	0.01690	0.00000	0.00000
Residual Sum (a)	1.0×10^{20}	0.01690	0.00000
Max Residual	0.13000	0.00169	0.00000
Node	KNOTEN2	KNOTEN2	KNOTEN2

2. **Initial Setup: Load factor (τ = 0.3).**
   - The load and, in some cases, generation values are increased based on the load factor (τ = 0.3).
   - Initial values after the first iteration: δ_2 = -0.013, V_2=1.0, λ=0.3000;
3. **Jacobian Matrix Calculation:**
   - Using the initial voltage values obtained from the external load flow calculation (δ2 = -0.013, V2 = 1.0, λ = 0.0000), the Jacobian matrix (Jaug) is computed.

$$\text{Jaug} = \begin{vmatrix} [9.9982 & -0.1300, & 0.1 \\ -0.1299 & 9.9988 & 0 \\ 0, & 0 & 1 \end{vmatrix}$$

4. **Tangent Vector Calculation:**
   - The tangent vector t is calculated by multiplying the inverse of the Jacobian matrix with the vector t= [0 0 1] ^{T}, where T denotes the transpose.

$$t = \text{inv}\ (\text{Jaug}) * \begin{vmatrix} 0 \\ 0 \\ 1 \end{vmatrix}$$

5. **Predictor-Corrector Steps:**

   With a step size factor (τ = 0.3), the first predictor step is performed, followed by the first corrector step.

   - First predictor step it_{1p}=ito + τ*t

$$\Rightarrow \quad \text{it}_{1p} = \begin{vmatrix} 0.0100 \\ 1.0000 \\ 0.3000 \end{vmatrix}$$

   - **First corrector step:** After correction, the updated values are: δ_2 = -0.0130; V_2 = 1.0002; λ = 0.3000;
   - **After two correction steps**, convergence is achieved, with the final values being δ_2 = -0.0130, V_2 = 0.9999, and λ = 0.3000.

The power calculation for λ = 0.0: K=1; Po=0.1, λ=0.0

→ P = Po (1 + K λ)= 0.1 * (1 + 1*0.0) = 0.1*100 = 10 MW

The values calculated using the **external program (Lastflussprogram)** are as follows:

Name of the load flow dataset: 2kn-0.dat

It: 1 It2: 1 Weight: 1.0000 Res.Sum.: 0.01000 Res.Sum.a: 100000000000000000000.00000
It2: 1 Weight: 1.0000 Res.Sum.: 0.01000 Res.Sum.a: 100000000000000000000.00000 Max.Res.: 0.10000 Node.KNOTEN2
It: 2 It2: 2 Weight: 1.0000 Res.Sum.: 0.00000 Res.Sum.a: 0.01000
It2: 2 Weight: 1.0000 Res.Sum.: 0.00000 Res.Sum.a: 0.01000 Max.Res.: 0.00100 Node.KNOTEN2
End of Program
Total time: 0.08333 min, Time without input: 0.00000 min
Enter 0 to end the program

Table 2. Load Flow Dataset Name: 2kn-0.dat

Iteration	1	2
Iteration Step	1	2
Weight	1.0000	1.0000
Residual Sum	0.01000	0.00000
Residual Sum (a)	1.0×10^{20}	0.01000
Max Residual	0.10000	0.00100
Node	KNOTEN2	KNOTEN2

This method generally results in stable convergence, similar to Possibility 1, provided the external program is reliable. However, discrepancies in the external calculations can introduce variability in the convergence process, potentially affecting the stability of the solution.
Using pre-computed results from an external load flow program can enhance the efficiency of the CPF procedure by eliminating the need for internal load flow calculations. While the predictor and corrector steps are executed effectively, the accuracy of the initial values is dependent on the quality and consistency of the external program used. This approach is particularly advantageous in scenarios where external tools are required or preferred. However, it introduces the risk of variability in convergence based on the performance of the external program.

In summary, this approach offers a practical and efficient alternative to internal methods, especially in real-world applications where external load flow calculations are commonly used. Nevertheless, the potential for convergence variability due to the performance of the external tool should be carefully considered.

3.4 Analysis of Results: Possibility 1, Possibility 2, and Possibility 3.

When we analyze these cases, we observe that:

1. **For λ = 0 (Possibility 1: Conventional Load Flow Start):**
   - After the first iteration (λ=0), the following values are obtained

     δ_2=−0.010, V_2=1.0, λ=0.0000,

     Two correction steps are required for adjustment.
   - After the second iteration (λ=0.3), the following values are obtained:

     δ_2=−0.0130, V_2=0.9999, λ=0.3000, Two correction steps are required for adjustment.

2. **For λ = 0.3 (Possibility 2: Direct CPF Start)**:

    ○ After the first iteration (λ=0.3), we obtain the same values as those obtained in the previous step

    $\delta_2=-0.0130$, $V_2=0.9999$, $\lambda=0.3000$,

    Three correction steps are required for convergence.

3. **For λ = 0.3 (Possibility 3: External Load Flow Program Start):**

    ○ After the first iteration (λ=0.3), the following values are obtained:

    $\delta_2=-0.0130$, $V_2=0.9999$, $\lambda=0.3000$,

    Three correction steps are required for convergence.

Comparison

- In all three cases, the final values after convergence are identical:

  δ2=−0.0130, V2=0.9999, λ=0.3000
- The external load flow approach (Possibility 3) eliminates the need for internal load flow calculations, improving efficiency. However, its reliability is contingent on the consistency of the external program.
- These results confirm stability and reliability across all methods.

Fig illustrating the relationship between voltage (V) and lambda (λ) for different Continuation Power Flow (CPF) initialization methods. The **blue line** represents Conventional Load Flow Initialization, which offers the most stable and accurate results. The **red line** shows Direct CPF Initialization, with slower convergence and less stability initially. The **green line** illustrates External Load Flow Initialization, which depends on the accuracy of the external tool and exhibits variable convergence behavior.

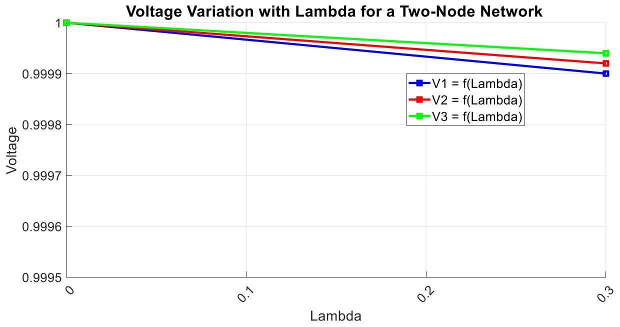

Fig. 3. Voltage (V) vs. lambda (λ) for different CPF methods: blue (Conventional), red (Direct), and green (External).

Table 3: Comparison of Load Flow Initialization Methods and Results

Parameter/ Method	Conventional Initialization	Direct CPF Initialization	External Program Initialization
Setup	K=1.0, Po=0.1, Y21=-10, Y22=10, V2=1.0, δ2=0°	Same as Conventional	Same as Conventional
Iterations	2	3	2
Final Results	δ2 = -0.013, V2 = 0.9999	Same as Conventional	Same as Conventional
Convergence	Quick	Slower	Similar to Conventional, tool-dependent
Stability	Very stable	Lower in early iterations	Stable, tool-dependent
Key Advantage	Efficient, accurate	Simplified setup	Eliminates internal calculations, relies on external tools

This shows that the conventional method is stable, while the direct and external program-based methods experience some instability in their initial steps but eventually achieve stability

Conclusions

This paper presents a comparative analysis of methods for initiating the Continuation Power Flow (CPF) procedure. The findings indicate that using conventional load flow calculations to initiate CPF provides the most stable and accurate results, ensuring reliable performance under various load and generation conditions. This approach facilitates robust convergence, efficient iterations, and consistent stability, making it the preferred choice for practical applications.

In contrast, direct CPF initialization, which bypasses prior load flow calculations, results in slower convergence and less accurate initial values. This necessitates additional iterations to achieve stability, sacrificing efficiency and precision despite simplifying the setup.

The use of external load flow programs has the potential to streamline CPF procedures. However, its reliability is contingent on the accuracy and consistency of the external tools, introducing variability into the convergence process.

In conclusion, the conventional load flow method remains the most stable and accurate for CPF applications. Future research should focus on improving convergence efficiency, particularly when integrating external tools, and exploring hybrid approaches to further optimize CPF performance.

The authors declare no conflict of interest.

***Authors**: Prof. Dr. Techn. Dipl. Ing. Agron Bislimi, UBT, University for Business and Technology, St. Calabria n.n. 10000, Prishtina, Kosovo. Email: agron.bislimi@ubt-uni.net*

REFERENCES

[1] Bislimi A., Influence of voltage stability problems on the safety of electrical energy networks, (2012). PhD Thesis, Institute for Electrical Systems and Energy Economics, Vienna University of Technology, Vienna.
[2] Ajjarapy V., "Computation Techniques for Voltage Stability Assessment and Control", (2006), Iowa State University Ames, Iowa, U. S. A.
[3] Ajjarapy V and Christy C: "The Continuation Power Flow: A Tool for steady state Voltage stability analysis.", (1992), Iowa State University. Ames, Iowa 50011 U.S.A.

[4] Bislimi A., Comprehensive Analysis of Power System: Exploring Load Factor, Power Balance, Active Load Variation, and Increment Factors with Iterative Implications, Vol. 15 No. 1, (2024), IJECES, https://doi.org/10.32985/ijeces.15.1.11 International Journal of Electrical and Computer Engineering Systems
[5] Bislimi A., Simplified Representation of Kessel/Glawitsch's Method, International Journal on Energy Conversion (IRECON)., Vol. 11 No. 6 (2023).
[6] Bislimi A., Continuous Power Flow Analysis in the Trigonometric Circle, Przegląd Elektrotechniczny, (2024) doi:10.15199/48.2024.09.24, ISSN 0033-2097, R. 100 NR 9/2024
[7] Bislimi A., Analysis of Convergence Behavior and Derivation of Divergence Indicator in Continuation Power Flow Iterations, International Journal on Energy Conversion (IRECON)., Vol. 11 No. 3 (2023), https://doi.org/10.15866/irecon.v11i3.23591
[8] Bislimi A., Illustration of the voltage stability by using the slope of the tangent vector component, IJECES, International Journal of Electrical and Computer Engineering Systems, Vol. 14 No. 6 (2023), https://doi.org/10.32985/ijeces.14.6.12, 2023
[9] Kundur P: "Power System Stability and Control" Proven solutions to problems in Electric power system stability and control, Electrical Engineering, McGraw-Hill
[10] Van Cutsem Th., Vournas C., Voltage stability of electric power systems, Norwell, MA Kluwer, (1998).
[11] Taylor, C. W., Power system voltage stability, McGraw Hill, (1994).
[12] Zeng L, Chiang H-D, Neves L. S, Fernando L (2023) On the accuracy of power flow and load margin calculation caused by incorrect logical PV/PQ switching: Analytics and improved methods, Volume 147, May 2023, 108905, International Journal of Electrical Power & Energy Systems.
[13] Kobibi Y I D, Djehaf M A, Khatir M, Ouadafraksou M (2022) Continuation Power Flow Analysis of Power System Voltage Stability with Unified Power Flow Controller Stability with Unified Power Flow Controller, Journal of Intelligent Systems and Control, Volume 1, Issue 1, 2022.
[14] Farid Karbalaei F, Abbasi Sh, Shabani H R (2023) The Continuation Power Flow (CPF) Methods, part of: Voltage Stability in Electrical Power Systems: Concepts, Assessment, and Methods for Improvement. Wiley-IEEE Press, DOI**:** 10.1002/9781119830634.ch5, p97-118
[15] Wang T, Wang Sh, Ma Sh, Guo J, Zhou X (2022) An Extended Continuation Power Flow Method for Static Voltage Stability Assessment of Renewable Power Generation-Penetrated Power Systems, IEEE Transactions on Circuits and Systems II: Express Briefs, DOI: 10.1109/TCSII.2022.3209335 ,IEEE, 2022
[16] Theil, G., & Demiri, B. (2007). Evaluation of lifetime distributions of medium-voltage network components for application in maintenance planning | Ermittlung der lebensdauerverteilungsfunktionen von ausgewählten betriebsmitteln elektrischer mittelspannungsnetze zwecks anwendung in der instandhaltungsplanung. *Elektrotechnik und Informationstechnik, 124*(6), 209–214.
[17] Theil, A., Theil, G., Theil, M. (2005). Medium voltage network reliability: Efficiency oriented supply restoration strategies. 15th Power Systems Computation Conference (PSCC).
[18] Fernandes. A. A., Freitas F. D., Ishihara J.Y., "Performance assessment of iterative linear methods for the computation of the power flow problem solution," Przegląd Elektrotechniczny, (2015) doi:10.15199/48.2015.09.63
[19] Sode-Yome A, Mithulananthan N.: „An economical generation direction for power system static voltage stability" Electric Power Systems Research 76, (2006), 1075–1083
[20] Theil, G. (1984). Fast second order load flow calculations | Schnelle Lastflussrechnungen zweiter Ordnung. *Elektrotechnik und Maschinenbau, 101*(9), 415–420.