

DETERMINING LOAD FLOW ANALYSIS FOR A HYBRID POWER SYSTEM USING NEWTON RAPHSON'S ITERATIVE APPROACH.

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Abstract

The integration of renewable energy sources in modern power system has led to the development of hybrid power systems, presenting unique challenges in maintaining stability and ensuring efficient power flow. This paper explores the application of Newton Raphson's iterative method for load flow analysis for a hybrid power system. The study focuses on optimizing power flow calculations, considering the intricate interconnections or multiple energy sources, such as solar, wind, and conventional sources, along with energy storage systems. The Newton Raphson approach is employed to iteratively solve the complex power flow equations, considering various constraints and components' characteristics. The paper delve into the mathematical formulation of the method, emphasizing its suitability for handling non-linear power flow equations in a hybrid power system context. Additionally, the study examines the impact of varying parameters, such as load demand, renewable energy availability, and system contingencies on the convergence and accuracy of Newton Raphson algorithm. The results demonstrate the efficiency of the proposed method in achieving load flow solutions for hybrid power systems, offering insights into system performance, stability, and potential enhancements in operational planning and management. The findings underscore the significance of utilizing iterative methods like Newton Raphson for load flow analysis in complex hybrid power systems, fostering more reliable and efficient integration of diverse energy sources.

Key Words: Newton Raphson, Solar PV, Generator, Wind Power and Power Systems.

1.0 Introduction

Up until recently, most power systems were unidirectional, transferring generated electricity from transmission systems to distribution systems, where customers are connected. However, there is now a bidirectional power flow because electricity may be produced and used within the distribution system [1]. EV charging stations might also act as generators to feed extra energy to the utility grid, while battery systems could act like loads when they are being charged. As a result, the system as a whole becomes more complicated and the electrical power system develops into an intelligent, AC/DC hybrid system. Given that existing distribution systems must evolve to accommodate the growing use of DC generators and loads, it follows that the conventional AC-oriented power flow analysis must also adapt to meet the new needs of a hybrid power system. Numerous studies on the AC/DC load flow are provided, with a focus on high voltage DC (HVDC) transmission systems, but these techniques are not convenient for hybrid distribution systems since they perform poorly in systems where DC bus penetration is significant, which makes the algorithm more complex. Future smart AC/DC distribution systems are likely to have numerous intersecting AC and DC nodes, branches, different AC or DC generators, and coupled loads, so decoupled methods that divide the main AC/DC grid into several sub-grids might not be appropriate to use for coupled AC/DC distribution systems [1]. Additionally, it is noted in [2] that the sequential technique is more difficult than the unified method, may sometimes have convergence issues, and requires

more time to solve since the whole AC solution must be computed each time a parameter on the DC side is changed. Additionally, it is shown for the sequential technique that as the number of repetitive loops rises, algorithm dependability declines and complexity increases [3]. Due to its quadratic nature, the Newton-Raphson iterative technique has the benefit that it converges more quickly than other methods. Since AC/DC distribution systems include AC and DC microgrids, this presentation has focused on an integrated technique for load flow analysis.

The suggested method contributes by using AC/DC voltage source converters to present a Newton-Raphson-based iterative method for overall systemlevel power transfers between AC and DC subnetworks, and by taking into consideration various connection types in a hybrid distribution system with DC/DC converters. The suggested load flow approach may acquire power flow across converters linked at various buses while accounting for all converter losses. By integrating AC and DC line flows, this technique reduces the complexity of the algorithm and has the benefit of a quicker convergence time with excellent accuracy when compared to other techniques. For AC/DC distribution systems, the researchers of [4] suggested a unified load flow analysis technique based on the reduced gradient method.

H-owever, the technique lacks models for DC/DC converters, and converter operating modes like constant voltage control and constant duty ratio are disregarded.

A-dditionally, DC/DC converters are used in constant duty ratio and constant output voltage modes. Because the equations provided are general, the suggested approach may be applied to various converter types [5].



Figure 1.0: World Total Solar Market Scenarios between 2018 and 2022 [7]



Figure 2.0: Representation of an AC Grid with DGs, Battery, and Loads [5]

Table 1.0: Effici	ency Comparis	son of a
Residential Fue	el Cell System	[6]
	Connected	Connected
	+ DC	

	Connected		nnected		Connected to	
	lu a DC System			an AC	System	
Device	Conver		Efficie	C	onver	Efficie
	sion		ncy	s	ion	ncy
	Stag	es	(%)	S	tages	(%)
Kitchen Applian ces	1	-	97.6		2	95.2
Home Electro nics	2	-	95.2		5	88.4
Lights- Fluores cence	2		95.2		4	90.6
Heating , Ventilat ion	1	-	97.6		2	95.2
- Laundry Applica	1		97.6		2	95.2

Nigerian Journal of Engineering Research Unicross (NJERU) ISSN No. 2971-785X 110 | P a g e

tion		
Weight	97.3	94.5
ed		
Average		

2.0: Hybrid AC/DC Distribution Systems

Following the discussion of pure AC and DC distribution systems, it is appropriate to bring up a third option that combines both, namely a hybrid one. The integration of renewable energy sources and energy storage systems necessitates fresh updates and creative solutions on the distribution network, even though the electrical system is changing to a more sustainable and environmentally friendly future.

By 2050, according to the International Renewable Energy Agency, renewable energy sources will supply more than 80% of the world's electricity, with wind and solar power plants accounting for 52% of that total [6].

Figure 2.9 shows how, under the reference scenario, total installed capacity may reach more than 8000 GW in 2030 and more than 12000 GW in 2050, with the majority of tremendous growth brought on by solar and wind energy. Solar and wind power generation capacity rises higher in the alternative doubling scenario than it does in the reference scenario. According to the remap scenario, which is depicted in Figure 10, oil will no longer be used to generate electricity in 2050, with renewable energy sources producing 82% of all electricity [6].

These forecasts show that as distributed generation becomes more prevalent, the electrical grid will become more decentralized.

To operate flawlessly, securely, and predictably, an electrical system needs to have an equilibrium between the generation side and the load side. Uncertainty around renewable energy sources is one of their drawbacks. Instantaneous weather circumstances have a significant impact on how they are generated.



Figure 3.0: A Representative Topology for an AC/DC Smart Grid [7] **3.0: Model Equations**

Consider a set of n nonlinear algebraic equations denoted by

 $F_i(x) = 0$ where $i = 1, 2 \dots n$,

Where n is the number of nonlinear algebraic equations in x

Where x is the design vector given as

Which can also be represented by

 $F_1(x_1 x_2 ... n) = 0 - - - - (1.2)$

We have our unknown as X_1, X_2, \dots, X_n suppose initial guess for the variables is given as

$$x^{0} = \begin{cases} x_{1}^{0} \\ x_{2}^{0} \\ \vdots \\ x_{n}^{0} \end{cases} - - - - - (1.3)$$

Initial guess may or may or be feasible we consider solutions close to values of the unknown The corresponding correction state are

 (Λr^0)

$$\Delta x^{0} = \begin{cases} \Delta x_{1}^{0} \\ \Delta x_{2}^{0} \\ \vdots \\ \Delta x_{n}^{0} \end{cases} - - - - - (1.4)$$

From the concept of Newton-Raphson method of solution, once the correction state is obtained and added to the guess values the real solutions can be obtained

Then

$$f_1 \left(u_1^0 + \Delta x_1^0 + \Delta x_2^0 , \dots , x_n^0 + \Delta x_n^0 \right) = 0 \quad - \quad - (1.5)$$

Equation 3.9 satisfies $i - 1, 2, \dots, n$ and using Taylor's series expansion we have that $f(x_0^0, x_0^0, x_0^0) \perp \frac{\partial fi}{\partial x_1^0} \mid \Delta x_2^0$

$$\frac{\partial fi}{\partial x_n} \left| \begin{array}{c} \Delta x_n^0 \\ x = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \end{array} \right| + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ \lambda = x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^0 \\ + \left| \begin{array}{c} \Delta x_n^$$

.

Also neglecting the higher order term

$$\begin{bmatrix} f_{1} (x^{0}) \\ f_{2} (x^{0}) \\ \vdots \\ \vdots \\ f_{n} (x^{0}) \end{bmatrix} = \begin{bmatrix} \frac{\partial f_{1}}{\partial x_{1}} & \frac{\Delta x_{1}^{0}}{x_{2}} & \frac{\partial f_{1}}{\partial x_{2}} \\ \frac{\partial f_{2}}{\partial x_{2}} & \frac{\Delta x_{1}^{0}}{x_{2}} & \frac{\partial f_{2}}{\partial x_{2}} \\ \frac{\partial f_{2}}{\partial x_{2}} & \frac{\Delta x_{1}^{0}}{x_{2}} & \frac{\partial f_{2}}{\partial x_{2}} \\ \frac{\partial f_{n}}{\partial x_{1}} & \frac{\Delta x_{1}^{0}}{x_{2}} & \frac{\partial f_{2}}{\partial x_{2}} \\ \frac{\partial f_{n}}{\partial x_{1}} & \frac{\Delta x_{1}^{0}}{x_{2}} & \frac{\partial f_{n}}{\partial x_{2}} \\ \end{bmatrix} \dots \dots \frac{\partial f_{n}}{\partial x_{n}} \begin{bmatrix} \Delta x_{n}^{0} \\ x = x^{0} \\ x = x^{0} \end{bmatrix} - (1.7)$$

Therefore

$$\begin{bmatrix} f_1(x^1) \\ f_2(x^0) \\ \vdots \\ \vdots \\ f_{n-}(x^0) \end{bmatrix} + \begin{bmatrix} \frac{\partial f_1}{\partial x_1} \Big|_{x=x^0} \frac{\partial f_1}{\partial x_2} \Big|_{x=x^0} \cdots \frac{\partial f_1}{\partial x_n} \Big|_{x=x_0} \\ \frac{\partial f_2}{\partial x_1} \Big|_{x=x^0} \frac{\partial f_2}{\partial x_2} \Big|_{x=0} \cdots \frac{\partial f_2}{\partial x_n} \\ \frac{\partial f_n}{\partial x_1} \Big|_{x=x^0} \frac{\partial f_n}{\partial x_2} \cdots \frac{\partial f_n}{\partial x_n} \Big|_{x=x^0} \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \\ \vdots \\ \Delta x_n \end{bmatrix} = 0 - z - z - (1.8)$$

Then
$$F^0 + J^0 \Delta x^0 = 0$$
 - - - - (1.9)

Where:

J is Jacobian matrix evaluated by taking partial derivative of x the design vector evaluated at x = 0 we also hence t-hat $\Delta x^0 = -[J^0]^{-1} F^0 - - - - - (2.0)$

Where Δx^0 is the correction state required to be added in the initial guess values to get the required solutions. S—a---y for first iteration initial guess value may be given as

$x^1 -= x^0 + \Delta x^0$	(2.1)
For R iteration we can write	
$x^{R} = x^{R-1} + \Delta x^{R-1}$	(2.2)

Taken from the previous iteration equation - (2.3) Also Δx^{R-1} can be calculated as $-\Delta x^{R-1} = -[J^{R-1}]^{-1} F^{R-1} - - - - (2.4)$ Take tolerance as To 1 = max { $F_1(x^1)_1 F_2(x^2) \dots F_n(x^R)$ } - (2.5) If Tol $\leq \epsilon$ which is within a tolerable range the solution converges.

4.0: Simulated Results and Discussions



Figure 4.0: A load flow simulated results

In figure 4.0 is the simulated output for the selected 16 buses for the power system. There are connected to the different substations either for DC or AC. The grid system does allow for iterative application of the Newton Raphson's rule. This simulation was made easy with the use of ETAP software. This tool makes it easy to simulate for the different load variations.



Nigerian Journal of Engineering Research Unicross (NJERU) ISSN No. 2971-785X 112 | P a g e

Figure 5.0: Load flow graph for bus 5 from MATLAB/Simulink

In figure 5.0 is presented the load flow for the selected bus 5. This load flow combines both voltage flow and current flow. The upper region represents the generated voltage output at bus 5. The two sinusoids line at the middle indicates the ripples generated as a result of the voltage propagation. The generated voltage for both AC and DC are evenly distributed, hence this indicates proper load shedding in the process. In the other hand, the lower region of figure 4.0 shows the generated current. This current is evenly distributed whether AC or DC. This uniformity indicates that the process lacks ripples as in the case of generated voltage. This voltage/current generating process was made possible with use of MATLAB/Simulink tools.



Figure 6.0: Performance simulation for standalone solar output

From figure 6.0 is the stand-alone simulated results for the solar PV output form. It shows the energy consumption in kWh as well as the solar power generated. At power generation of 5kW, power consumed is perked at 25kWh. At generated power of 15kW, power consumed was at 18kWh then at generated power of 30kW, power consumed was at 21kWh. This rise and fall in the generated power with respect to the power consumed is a result of the difference in sunlight due to weather changes. It can never be fixed but varied constantly. This graphical output demonstrates what happens in the process when only the DC source is connected to the grid. This was made possible with the use of Python programming tools.



ᢤ Figure 1



Figure 7.0: Performance simulation for standalone generator output

The simulated output form for stand-alone generator is shown in figure 7.0. The generated power from the AC generator is maximum at 30kW, the power consumed at 8kWh. At generated power from the generator of 5kW, the power consumed was 4.5kWh. At generated power from the generator of 15kW, power consumed was 8kWh. Then power generated at 30kW, power consumed was 10kWh. The variations in the power generated and consumed by the AC generator is due to losses in the generator and as well as variations in the external loads. This is a physical phenomenon that is applicable to all generating sets when energized and connected to loads. This simulation was achieved through the use of Python programming tools.



Figure 8.0: Hybrid performance output simulation for DC/AC

Figure 8.0, displays the hybrid performance of the simulated output performance for the solar PV/Generator which represents the AC/DC generated and connected to the grid. The maximum combined power/hour generated was 700kW. The maximum power consumed is 600kWh. The simulated result showed that there was an even distribution of power generated whether AC/DC. This is to ascertain the facts that hybrid power systems are more stabilized than these stand-alone power system. It gives more reliable smart grid connected system than the stand-alone. At the lower part of figure 6.0 is the ripples which are associated with voltage sources.

5.0: Conclusion

Carrying out load flow analysis with the aid of Newthon-Raphson iterative approach is faster and easier as compared to Gauss Sidel method. The Newton-Raphson iterative approach is a powerful tool for load flow analysis in hybrid power systems. It offers adaptability and accuracy, though its potential stability and computational demands under some conditions calls for attention and refinement. The simulated work showed the voltage and current generated relationships for AC alone, DC alone and AC/DC combined output together. It was shown that a hybrid performance output is far more reliable than the stand-alone power system. The simulated Hybrid Power System Efficiency is 87.50%. This is very ideal for a renewable energy source.

6.0: References

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