SPREADSHEETS in EDUCATION

Bond University

Volume 12 | Issue 1 | 2019

Power System Load Flow Analysis using Microsoft Excel – Version 2

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Power System Load Flow Analysis using Microsoft Excel – Version 2

Abstract

This paper presents version 2 of a previously published spreadsheet tool "Microsoft Excel based Power System Load Flow Analysis (MSEBPSLF)". This improved version is designed and developed based on user feedback, requests and additional requirements. The data input process is simplified by removing graphical user interface screens. A few operational challenges have also been eliminated. Additional features and sample systems have been added to provide a head start for the users. Version 2 is implemented on the latest versions of MS Windows operating system and MS Office platforms. Simple and small networks, besides IEEE standard networks have been studied and results have been provided for demonstrating the effectiveness of version 2.

Keywords: Microsoft Excel, Power System Analysis, Load Flow Studies, Visual Basic for Applications (VBA)

1. Introduction

Load flow (or Power Flow) studies is an important topic in Electrical Power engineering. This topic is taught to both technology and engineering students as a module or even a full course. Teaching methodology for this course varies from university to university. Most common methods of load flow studies that will be taught are Gauss-Seidel, Newton-Raphson, Fast-decoupled Newton-Raphson and DC Load Flow. Generally, theoretical treatment of load flow methods will be covered in classroom lectures with mathematical equations; followed by solving the load flow equations up to first iteration of each method. In a majority of the cases, students are trained on the computers with any software, such as PowerWorld, DigiSilent, InterPSS, Simpow and many more. These all are well-known commercial software packages and can be customized to user requirements. Laboratory exercises include different power networks, including standard IEEE networks. Such commercial applications usually support wide ranging power system studies such as Load flow studies, short circuit studies, stability analysis, optimization studies etc., and even come with a library of standard networks. Naturally, first time users may need significant training to understand a typical commercial application.

Students of engineering programs are generally expected to write code by themselves and then test their code to compare the results with those of any software that is properly benchmarked. Power system load flow study being a basic study and its output is required for other studies. So, engineering students write their own programs to generate output according to their own requirements. Usually MATLAB, C or C++ are the preferred languages for this task. While MATLAB provides a powerful platform for programing complex computations and plotting the graphs; the languages C/ C++ need more efforts in coding as built in functions may not be as friendly in MATLAB. Thus, programmers will have varied experiences on the chosen programming platforms to develop solutions for load flow studies. And then students need a software that provides them intermediate results to verify their own code. The spreadsheet presented in this article comes in handy, as it is available for free.

MS Excel as a product itself is very simple, user-friendly and intuitive to the users. A few MS Excel based power system solutions have already been reported (Acarnley (2005); Zeljkovic and Gacanovic (2006); Lau and Kuruganty (2008); Sastry and Ramkhelawan (2012)). Spreadsheets can be effectively used to store the data, carry out computation and then to display the output as needed. It is even convenient for plotting graphs. MS Excel uses Visual Basic for Applications (VBA) for programming and even complex computations can be coded just as with other programming languages. VBA even supports complex numbers and matrix manipulations through its built-in functions. Load flow studies require complex number and matrix manipulations. However, programmers can write their own libraries if not satisfied with VBA built-in features.

The core objective of this paper is to present an improved version of our previous "Microsoft Excel based Power System Load Flow Analysis" (MSEBPSLF) which was previously published. The organization of this paper is divided into eight sections. Section 1 provides broad introduction, Section 2 provides rationale for bringing out the version 2 of our previous solution. Modifications, design features and instructions on how to use this spreadsheet are provided in sections 3 and 4. This improved version does come with a few new networks, particularly to assist students in understanding the basics. Small systems from well-known textbooks and even IEEE standard networks have been provided. A few illustrations and case studies are provided in section 5. Section 6 provides limitations of our spreadsheet model and some aspects that were observed from the users of previous version. Finally, section 7 concludes the discussion.

2. Rationale for a revised version

The major reasons for a revised version are user feedback and changes in technologies over time. The first version of this spreadsheet was made available during 2012 (Sastry and Ramkhelawan, 2012). Since 2012, there have been several changes in underlying software platforms, such as MS Office and MS Windows etc. We, the authors received feedback on the version 1 of the spreadsheet from users all over the world with appreciations and suggestions for improvement. While the user feedback is mostly appreciative, however a few bugs and operational challenges were also notified. Importantly, users wanted more sample networks and additional features. Further, the authors themselves have tested the application, collected user feedback while using spreadsheet in the regular the classroom teaching. It is evident that the previous version of MSEBPSLF spreadsheet has been extensively used for various purposes. In general, the users are mostly comprised of teachers, undergraduate, graduate students and practicing engineers. All categories of users have expressed significant interest in the spreadsheet tool for carrying out load flow analysis. The changes in technology platforms and user feedback are summarized below.

a. Changes in the underlying software platforms

The previous version of MSEBPSLF spreadsheet (Sastry and Ramkhelawan, 2012), was developed on MS office 2010 on MS Windows 32-bit operating system. Over the years, there have been several changes in the underlying platforms. As of now, MS office 2019 version is released, and newer versions of operating systems were also released. Now, the combination of 64-bit processors and 64-bit MS Windows 10 operating system is almost becoming a standard. Not surprisingly, users who are using latest platforms faced challenges in using our previous version. Hence, from the software maintenance point of view, all existing 32-bit applications need to be upgraded or re-coded to operate properly on 64-bit systems and platforms; and our spreadsheet is no exception. A few users were able to edit the code to make it work on 64-bit systems. However, it should be noted that not all users will be able to do the same; as such maintenance would require a good understanding of VBA programming.

b. Minor bugs and operational challenges

There have been a few bugs in the previous version. Some are reported by users. We sincerely thank their efforts in finding bugs and operational challenges. Bugs reported are mostly about the missing data. For instance, previous version requires the user to provide number of buses and number of lines of the system in the respective data screens. Earlier version used to stop working when such data is not supplied. A major suggestion is the complete removal of graphical user interface (GUI) screens for system data. This aspect is not really a bug, so we consider this as an operational challenge.

The previous version has an elaborate GUI which can (also) be used to input bus and line data of the systems. System data also can be copied from elsewhere and pasted into respective sheets in bulk. In other words, GUI is an alternative feature. However, a majority of the users felt that this is not a desirable feature and even leads to confusion. Users simply wanted to input the data directly into the cells of the spreadsheet; whereas the GUI requires many clicks and hence a lot of time needs to be spent, as the data can only be submitted only line by line. This request of removing the GUI is more predominant in case of users dealing with big systems or data of existing systems in other software packages. Such users simply want to copy and paste the data from the source into the spreadsheet. There were a few suggestions on removing a few columns in line data as some columns are not used in normal cases. It should be noted that IEEE standard data format was used in developing this solution keeping in line with the IEEE standards. However, using such standard data format itself is not mandatory according to IEEE standard (IEEE, 2015) itself.

c. More example networks and detailed analysis

Users who provided feedback consisted of teachers, students and researchers and they naturally have different expectations and hence different requirements. Most teachers expressed a desire for including more sample networks especially standard IEEE networks and those from standard textbooks. PV bus treatment and formation of Jacobian matrix are of particular interest. However, it should be noted that size of Jacobian increases significantly with the number of buses and thus providing the entire matrix (or even sub matrices) in the spreadsheet becomes difficult. Though the size of the Jacobian remains the same, values of the elements will be different in every iteration. Specifically, users requested the full Jacobian matrix during the first iteration, as there are some studies that keep the Jacobian constant and carryout the rest of the iterations to avoid computational burden (Lea and Kai (2017)). This request for full Jacobian at the end of the first iteration, for small systems is now incorporated as a feature in the version 2.

On the other hand, students wanted several examples on small size systems with different conditions, such as, a small system with a PV bus; intermediate results such as Y-Bus, values related to PV bus treatment, value of Jacobian matrix, comparison of results and plots showing variation of parameters etc. We as teachers have observed large systems with rows of data can be intimidating to the students due to sheer volume and size of the information (Grinberg et al (2016)).

We have observed a few aspects while using the version 1 of spreadsheet in classroom. Typically, undergraduate students would look for values of bus voltages at the end of first iteration since they were expected to do hand calculations. Graduate students would want to know values of line flows, losses, slack bus powers etc.; and variation of some or all of these parameters over the iterations. Graduate and research students wanted to make amendments to the code to suit their further investigation requirements. Practicing engineers looked for features such as parallel lines, support for two transformers connected in parallel, system components such power stabilizers, phase shifters, shunt capacitor banks, HVDC links, underground cables etc. Also, system studies like shunt capacitor sizing, location; reactive power compensation, contingency analysis and cost benefit analysis for various operating conditions were expected to be part of this spreadsheet. It is natural for practicing engineers to look up to a tool that can assist in their professional work. It is observed that procedures, practices and requirements of field engineers significantly vary from place to place and / or utility to utility. In most situations, field engineers have to deal with composite systems with different control elements and diverse power system elements such HVDC line, FACT devices etc. Then, they would have to do a lot of data processing before and after using any tool. *Interestingly, MS Excel was the most preferred tool for all engineers for pre and post processing of the data irrespective of the type of software that was used*[1]. It is very common to see the requirement of developing case studies with various scenarios and then an extensive cost benefit analysis. Comparison of various load flow methods is not of major interest to practicing engineers, but they are more interested in the application, post-processing, end-use of load flow data, particularly for cost-benefit studies.

[1] Italics by editor.

However, a few major aspects should be noted here. a) our spreadsheet was designed and developed for students and not entirely for utility engineers. b) this spreadsheet was not a commercial application in which support for more control elements such as power stabilizers, phase shifters etc can be expected. c) Application studies that use load flows such as cost-benefit analysis, case comparison etc are out of scope of our spreadsheet tool. If the requirement is to study a large size system where several different power component and control elements exist; then it is recommended that any standard / appropriate commercial product be used. Keeping in view of the above, an attempt is made to upgrade and revise the previous version of spreadsheet.

3. Design of the revised version

a. Improvements and Additional Features

The previous version of the spreadsheet MSEBPSLF (Sastry and Ramkhelawan; 2012) was developed with the specific objective to assist in classroom / laboratory in a typical academic environment used both by teachers and students. It also provided intermediate values and bar / lines plots analyzing and comparing different load flow studies. These features are still available and further enhanced in version 2. The front page of the revised spreadsheet is shown in figure 1.

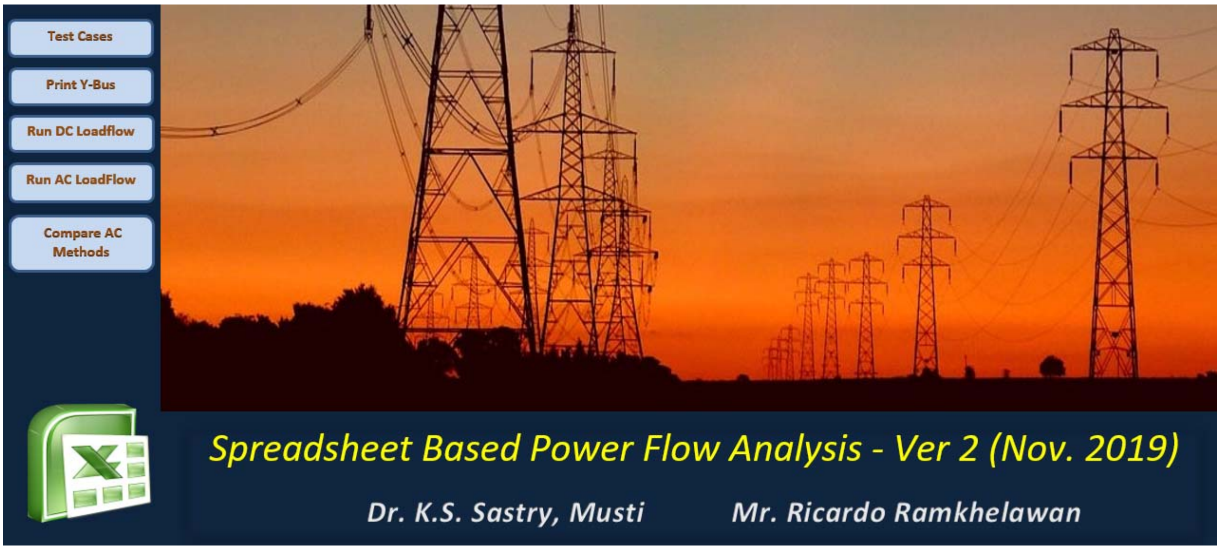

Figure 1. Front page of the "Microsoft Excel based Power System Load Flow Analysis"

As noted elsewhere, important improvements that have been made in version 2 include more test systems, additional features and a number of bug fixes. The new version of the spreadsheet will present details of Jacobian matrix; PV bus treatment. The GUI for data inputs is removed. Also, the present version 2 comes with two examples from the regular textbooks and four standard IEEE networks (IEEE 9, 14, 30 and 57). The data files of these networks are kept in a separate folder. Users can visit the 'Test Cases' page of the sheet and simply click on the system that they want to study, upon which the data of that chosen system will be displayed on the same page below. Users can examine the data and then transfer the same to input pages with a simple click again. The new version is tested on both 32bit/ 64 bit Windows operating systems and for MS office 2016 / 2019 platforms.

b. User-friendly interface

User interface and 'look and feel' from the previous version have been retained more or less; as users seem to be satisfied with the same. There are different pages or sub-sheets in the spreadhsheet to present the data and information in a modular fashion. These sub-sheets include CoverPage, Bus_Data, Branch_Data, Y_Bus etc., and the last page is Test_Cases. Input data in the pages 'Bus_Data' and 'Branch_Data' are very essential, without which spreadsheet will not be able to operate at all. Any changes to the position, names or/and edits to the individual sub-sheets or to the structure of the spreadsheet will result in malfunction. It is strongly recommended that first time users spend a few minutes to understand the overall structure of the spreadsheet itself.

a. Data input and output

Bus types and codes are simplified in version 2 as can be seen from Table 1. The bus type 'regulated generator bus' is avoided. For every bus, numerical code corresponding to the type of the bus needs to be provided. For bus type 2, which is PV bus; users are expected to provide minimum and maximum reactive power limits for obvious reasons.

Table 1: Bus Types and Codes

Bus Code	Bus Type Description	Letter notion
0	Load Bus	PQ bus
2	Voltage Controlled Generator Bus	PV bus
3	Slack/Swing Bus	Reference bus

Similarly, for branch data, an appropriate numerical code corresponding to the type of the branch needs to be provided. Table 2 provides numerical codes for different types of line sections. Branch data format follows more or less IEEE recommended data format, except for a few columns. Hence, users need to pay attention to the columns in the branch data.

Table 2: Section Types and Codes

Section Code	Section Type Description
0	Transmission Line
Transformer	
1	Fixed Voltage Ratio and/or Fixed Phase Angle
Side No.	Description
0	The controlled bus is one of the t/f terminals
1	The remote controlled bus is near the tap side
2	The remote controlled bus is near the impedance side
Circuit #	Description
1	Single Line
2 to 9	Used for Numbering of Parallel Lines

a. Implementation of the design and VBA Programming

A significant portion of the source code from the previous version is used with enhancements and adjustments wherever necessary. Overall source code is divided into several sections, functions and macros to facilitate modular structure and re-usability of the code. Code that was specific to 32bit systems is now updated to suit both 32-bit and 64-bit systems. Table 3 provides list of some selected modules and subroutines along with the description to provide insights to the enthusiastic programmers who may want to modify the application.

Table 3: Modules, Subroutines and their descriptions

Module Names & Subroutines	Description
LoadTestCases Subroutines: Import_CaseData_**n**Bus, send_TestCaseData, clear_TestCaseSheet.	This module facilitates the selection of test case networks. First the user selects a sample network for study and the case data is imported for screening. The implementation of this data input method is centred on MS-Excel's OpenText workbook function. The user can then accept or modify individual bus and/or branch data records as required and then transfer same into the respective Bus_Data and Branch_Data Worksheets to perform a load flow study.

BusData / BranchData Subroutines: get_BusData /get_BranchData; clear_BusData / clear_BranchData	These modules read data from the Bus_Data / Branch_Data Worksheets by parsing each record in turn and enter them into arrays for use by other modules.
GaussSeidel; Subroutines:PF_gs; print_GS_Results;	This module performs a Gauss-Seidel Load Flow using rectangular coordinates. The results of the study are presented on the GS_Results Worksheet. Intermediate results and performance metrics are also made available on the Bar_Plots and Line_Plots Worksheets. Instances of PV Bus type switching are posted on the PV_Bus_Treatment Worksheet.
NR_Jacobian Subroutine: Form_Jacobian	This module evaluates the elements of the Jacobian matrix used in the Newton-Raphson Load Flow method. The computed matrix for the first iteration is outputted on the Jacobian Worksheet. The sub matrices JI, J2, J3 & J4 are colour coded for ease of identification.
LineFlows Subroutines; calc_lineflows	This module calculates the real and reactive power flows through lines and transformers, using the complex voltages from the results of the load flow methods.

4. Instructions for using the version 2 spreadsheet

a. Overview of the process flow within the spreadsheet application

Version 2 process flow is similar to the previous version with a few changes. Figure 2 provides overall process flow that user are expected follow for better usage experience. As can be seen from figure 2, users can either chose to study the sample networks or submit the data of their own networks. Once the bus and line input data is available, then simply proceed to form the Y-bus and then for respective load flow pages to execute the built-in algorithms. Output pages will provide the values of output parameters, various graphs and charts etc.

b. Studying the sample networks

Firstly, users should check their system configuration as per the requirements specified by Microsoft (2016) for using the MS Office product, though, this revised spreadsheet is tested with MS Office 2010 and MS Office 2016; both x86-bit or x64-bit platforms. The specified requirements are at the minimum, so higher RAM and better processor are recommended, especially if the machine is running other programs that might be resource hungry. Then the version 2 of the spreadsheet itself, can be downloaded for free from the website of the journal - Spreadsheets in Education (SiE) https://sie.scholasticahq.com Users also need to download another file "samples.zip" and extract the contents.

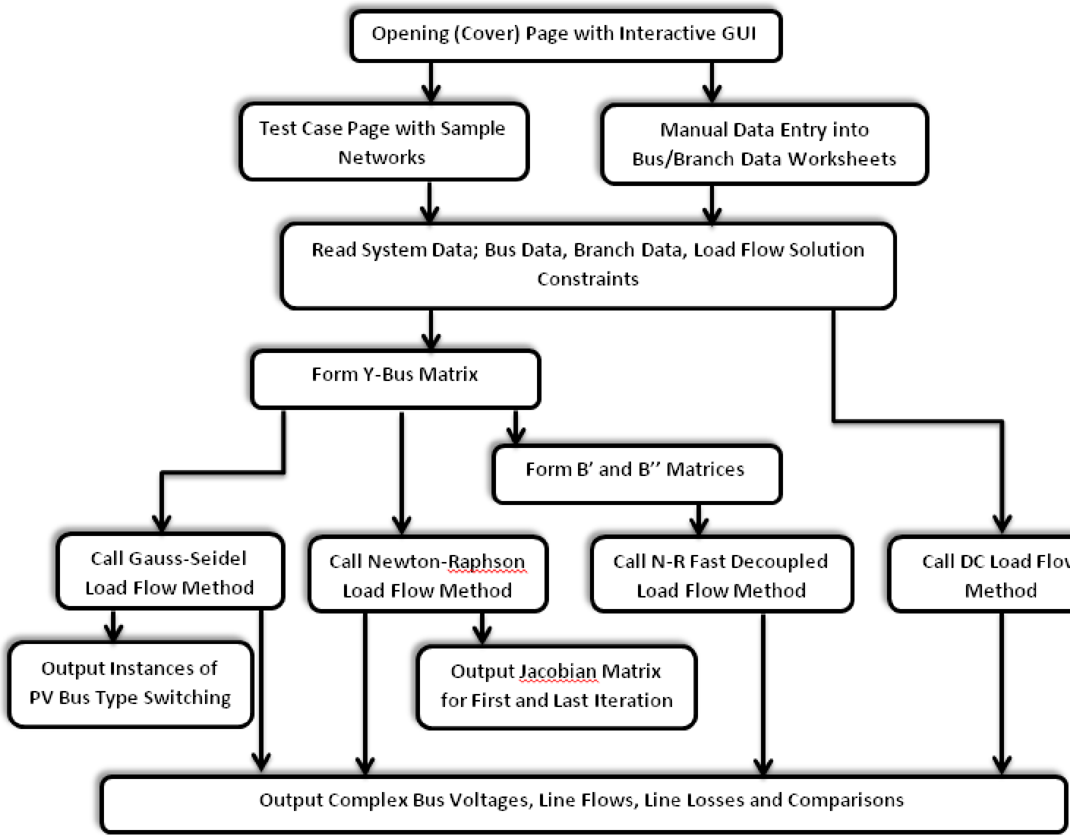

Figure 2. Process flow within the application

Before start using this spreadsheet, users also need to download sample networks (zip archive available on the same web page as that of the spreadsheet) and make them available in the same folder. This zip archive has one directory (sample networks) in it, which needs to be extracted into the same path as the spreadsheet. Some archive applications may create another extra folder while extracting. If that happens, users need to move the directory into the same folder where the spreadsheet is located. This folder contains a few sample networks from which users can choose as and when they need to study. Figures 3 and 4 show the location the folder named 'Samples' and the contents of the same folder as well. It should be noted that the spreadsheet should be located in the same folder where 'Samples' directory is located. Specifically, in the above example, the spreadsheet should be kept in the 'Downloads' folder, and not within the Samples folder. Changes made to the data inside the spreadsheet will not be reflected onto the data inside the folder, thus preventing unnecessary overwriting of the original contents.

To study any sample network, click on the 'Test Cases' button on the front page menu (or simply go to the sub-sheet named 'Test_Cases'), then user will be taken to the last page, where test cases can be selected from a drop down menu. Refer to figure 5. Once the required network is selected, then click on 'Load Test Case Data'. Application loads the both bus and branch data into the same page just below the buttons as shown in figure 5. After reviewing the data, users need to click on 'Send to Bus and Branch Data sheets' button so that this data is populated to the respective input sheets. Once the data is available in the input sheets, the application is ready for analysis and users can visit the respective sheets to execute the load flow. Based on user feedback, two additional features have been added.

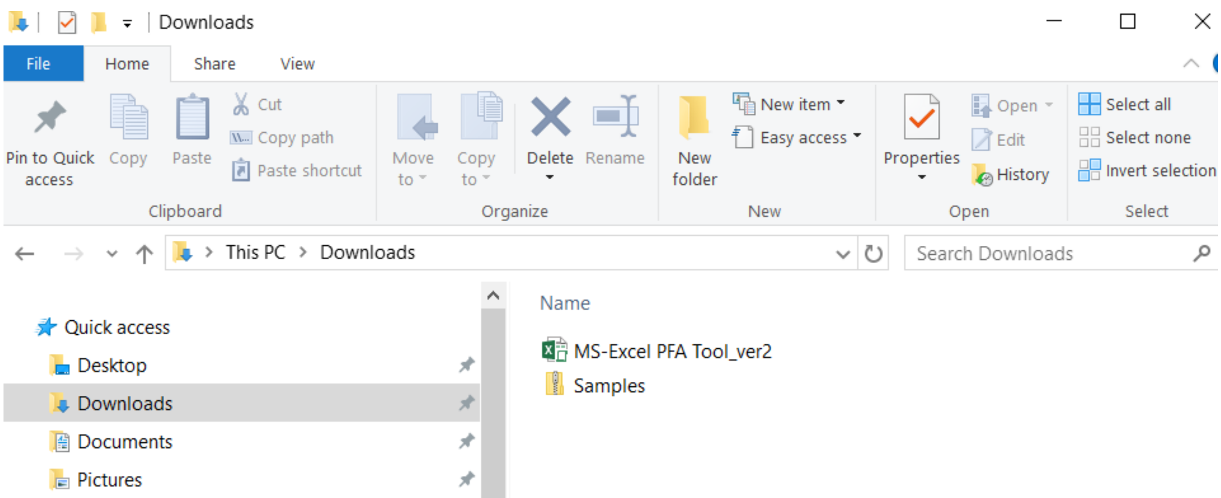

Figure 3. Location of the folder 'samples'

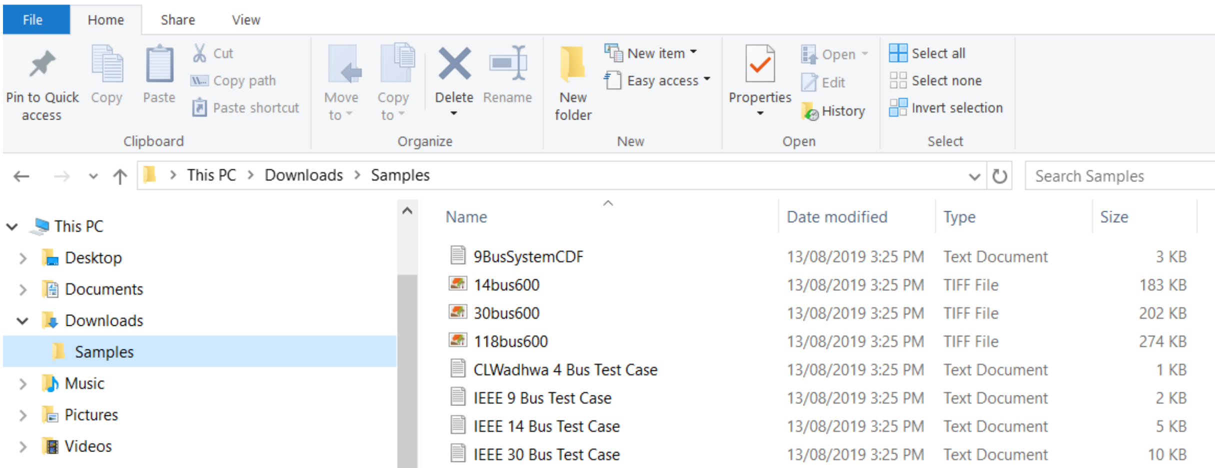

Figure 4. Sample networks inside the folder

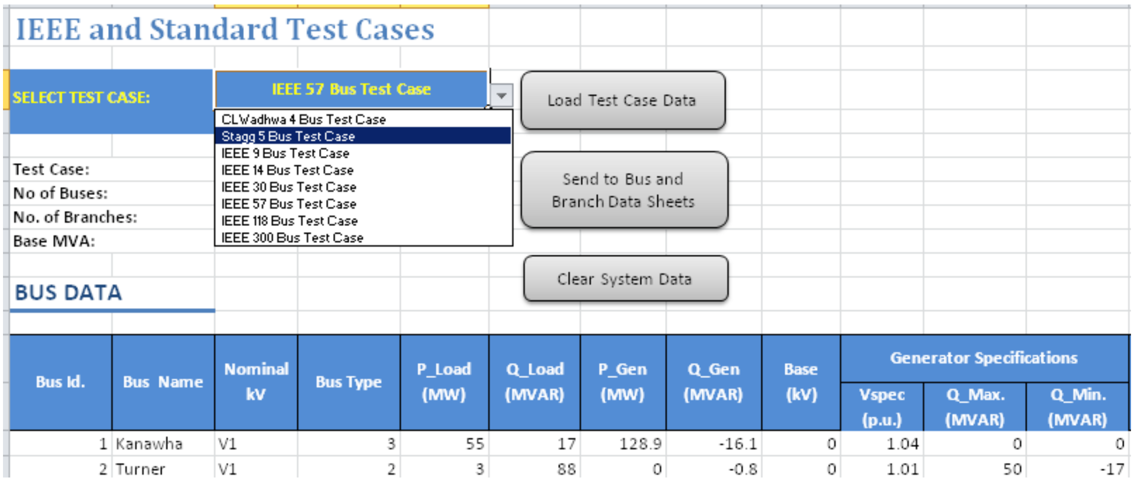

Figure 5. Selection of sample networks on the 'Test Cases' pagge

With version 2, users can now generate the entire Jacobian matrix and also intermediate computation stages in PV bus treatment. Jacobian matrix is divided into four sub matrices J1, J2, J3 and J4 and the spreadsheet displays these sub-matrices in different colors for ease of identification. Version 2 uses polar form of NR method so as to support decoupled load flow studies and hence the values of Jacobian.

5. Case Studies

This section provides a few case studies carried out using two networks from textbooks (Wadhwa, 2008; Stagg and El-Abiad, 1968). Results from textbook and the spreadsheet are shown in tables side-by-side for comparison purposes.

a. Stagg and El-Abiad Chapter 8: Load Flow Studies – 5 Bus System

Section 8.5 of this textbook presented a simple 5 bus system with partial solutions. This system has 1 Slack Bus, 1 Generator Bus (PV Bus) and 3 Load Buses (PQ Buses) (acceleration factor α = 1.4). Table 4 provides comparison of bus voltages at the end of first iteration. This comparison is considered as important due to the fact that textbook provided detailed numerical substitutions and the results. Table 5 provides the same, but at the end of tenth iteration.

Table 4: Stagg 5-bus system Voltages at the end of first (1st) Iteration using G-S Method

Iteration Count = 1; α = 1.4						
		Bus Voltage				
		Textbook			MSEBPSLF Ver2	
		Rectangular	Polar		Polar	
Bus No.	Bus Type		|V|	δ	|V|	δ
2	PV	1.05253 + j0.00406	1.053	0.221	1.053	0.22
3	PQ	1.00966 - j0.01289	1.01	-0.731	1.01	-0.732
4	PQ	1.01579 - j0.02635	1.016	-1.486	1.016	-1.486
5	PQ	1.02727 - j0.07374	1.03	-4.106	1.03	-4.106

Table 5: Stagg 5-bus system Voltages at the end of tenth (10th) Iteration using G-S Method

Iteration Count = 10; α = 1.4						
		Bus Voltages				
		Textbook			MSEBPSLF Ver2	
		Rectangular	Polar		Polar	
Bus No.	Bus Type		|V|	δ	|V|	δ
2	PV	1.04623 - j0.05126	1.047	-2.805	1.048	-2.806
3	PQ	1.02036 - j0.08917	1.024	-4.994	1.024	-4.995
4	PQ	1.01920 - j0.09504	1.024	-5.327	1.024	-5.327
5	PQ	1.01211 - j0.10904	1.018	-6.149	1.018	-6.149

From tables 4 and 5, it can be seen that spreadsheet values match those with the values provided in the textbook. Most users needed this demonstration of benchmarking before they can start using this application. Now, table 6 provides values of line flows (to-from and from-to) for comparison purposes. Users should note that this spreadsheet considers bus loads (P and Q) as positive and generations as negative. Then per unit system is used and the values provided here are in actual values, for comparison purposes.

Table 6: Stagg 5-bus system line flows at the end of tenth (10th) Iteration using G-S Method

Iteration Count = 10									
		Line Flows							
		To-From				From - To			
		Textbook		MSEBPSLF Ver2		Textbook		MSEBPSLF Ver2	
From Bus	To Bus	MW	MVAR	MW	MVAR	MW	MVAR	MW	MVAR
1	2	88.8	-8.6	88.82	-8.68	-87.4	6.2	-87.41	6.25
1	3	40.7	1.1	40.7	1.13	-39.5	-3	-39.51	-2.99
2	3	24.7	3.5	24.67	3.54	-24.3	-6.8	-24.32	-6.78
2	4	27.9	3	27.93	2.96	-27.5	-5.9	-27.48	-5.93
2	5	54.8	7.4	54.82	7.36	-53.7	-7.2	-53.7	-7.19
3	4	18.9	-5.1	18.93	-5.16	-18.9	3.2	-18.89	3.17
4	5	6.3	-2.3	6.34	-2.28	-6.3	-2.8	-6.31	-2.84

Now, for the same system, solution using N-R Method can be examined. Textbook has used rectangular coordinates and MSEBPSLF Ver2 uses polar coordinates as indicated earlier. Tables 7 and 8 show full Jacobian matrix from the textbook and from the spreadsheet respectively. It is interesting to see that the sub-matrices J1 (from the textbook) is same J2 from the spreadsheet and the same with J2 and J3.

Table 7: Jacobian matrix for Stagg 5-bus (rectangular coordinates) from the textbook

10.53334	-1.66667	-1.66667	-2.5	33.4	-5	-5	-7.5
-1.66667	12.84167	-10	0	-5	38.975	-30	0
-1.66667	-10	12.91667	-1.25	-5	-30	38.75	-3.75
-2.5	0	-1.25	3.75	-7.5	0	-3.5	11.25
31.43	-5	-5	-7.5	11.13334	1.66667	1.66667	2.5
-5	38.415	-30	0	1.66667	-12.9917	10	0
-5	-30	38.64	-3.75	1.66667	10	-12.9167	1.25
-7.5	0	-3.75	11.17	2.5	0	1.25	-3.75

Table 8: Jacobian matrix for Stagg 5-bus (rectangular coordinates) as computed by MSEBPSLF Ver2

33.4	-5	-5	-7.5	10.53333	-1.66667	-1.66667	-2.5
-5	38.975	-30	0	-1.66667	12.84167	-10	0
-5	-30	38.75	-3.75	-1.66667	-10	12.91667	-1.25
-7.5	0	-3.75	11.25	-2.5	0	-1.25	3.75
-11.1333	1.66667	1.66667	2.5	31.43	-5	-5	-7.5
1.66667	-12.9917	10	0	-5	38.415	-30	0
1.66667	10	-12.91667	1.25	-5	-30	38.64	-3.75
2.5	0	1.25	-3.75	-7.5	0	-3.75	11.17

b. CL Wadhwa 4 bus system for Jacobian and PV Bus system

C L Wadhwa Chapter 18 (Wadhwa 2008), presented a simple 4 bus system with partial solutions. This system has 1 Slack Bus, 3 Load Buses (PQ Buses) (acceleration factor α = 1.6). Table 9 provides comparison of bus voltages at the end of first iteration. Refer Example 18.1 of the textbook for details.

Table 9: Wadhwa 4-bus system Voltages at the end of first (1st) Iteration using G-S Method

Example 18.1 (α = 1.6)						
		Bus Voltage				
		Textbook			MSEBPSLF Ver2	
		Rectangular	Polar		Polar	
Bus No.	Bus Type		|V|	δ	|V|	δ
2	PQ	1.01899 - j0.046208	1.02	-2.596	1.02	-2.597
3	PQ	0.994119 - j0.0467968	0.992	-2.705	0.992	-2.705
4	PQ	*0.954565 - j0.1034944	0.96	-6.188	0.984	-6.363

*arithmetical errors in text book calculation

Example 18.2 of the textbook changes one of the PQ buses as PV bus and the reactive power limits are given by 0.1 ≤ Q2 ≥ 1.0 and α = 1.0; Table 10 provides a comparison at the end of first iteration.

Table 10: Wadhwa 4-bus system Voltages at the end of first (1st) Iteration using G-S Method, with PV bus

Example 18.2 (α = 1.0; 0.1 ≤ Q2 ≥ 1)						
		Bus Voltage				
		Textbook			MSEBPSLF	
		Rectangular	Polar		Polar	
Bus No.	Bus Type		|V|	δ	|V|	δ
2	PV	1.0395985 + j0.02891158	1.04	1.593	1.04	1.594
3	PQ	0.9978866 - j0.015607057	0.998	-0.896	0.998	-0.896
4	PQ	0.998065 - j0.022336	0.998	-1.282	0.998	-1.281

A special note on PV bus treatment is that, users can change the reactive power limits and see how the output and particularly the convergence change from case to case.

However, it should be noted that reactive power limits for a generator are range bound and hence the changes in the spreadsheet are only meant for theoretical purposes or designing or planning a new system altogether.

In addition to the numerical output of the load flow studies, version 2 offers comparison of various load flow methods. This feature is enhanced and simplified from the previous version. Figures 6 and 7 graphically present the comparison of parameters when different load flow studies are applied to 4-bus and 5-bus systems. From the figures it can be seen that all the methods converge and agree as far as the final solution after convergence is concerned.

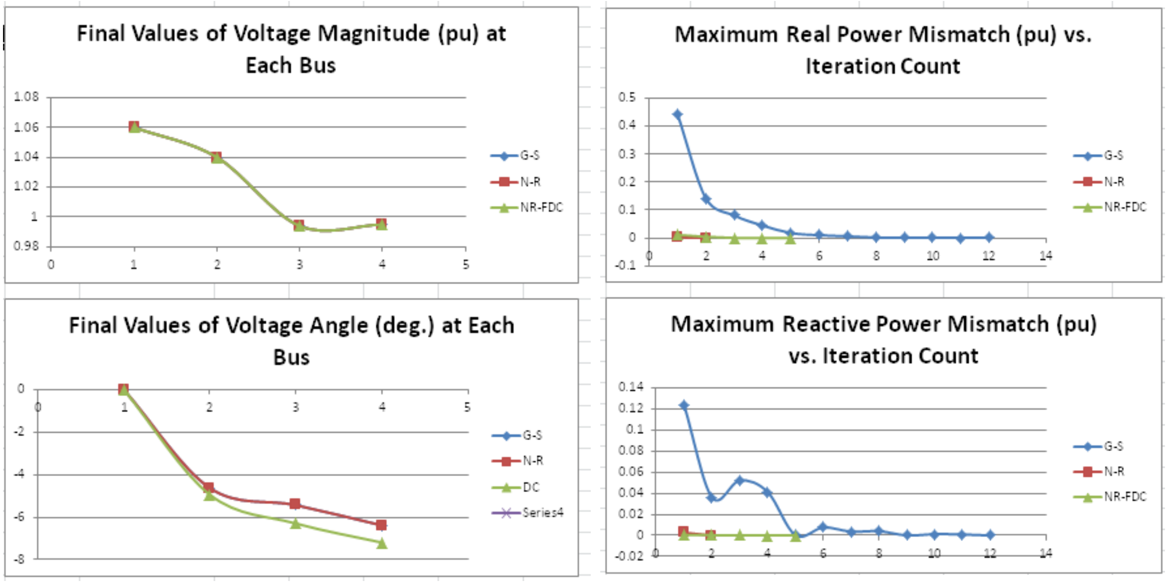

Figure 6. Comparison of LF algorithms for Wadhwa 4-bus system

From the above, it can be seen that different algorithms of loadflow as coded in the spreadsheet work satisfactorily and thus produce agreeable results. However, complex and /or composite power networks may pose challenges in obtaining the convergence due to the fact that this spreadhseet does not make any adjustments for convergence during the execution.

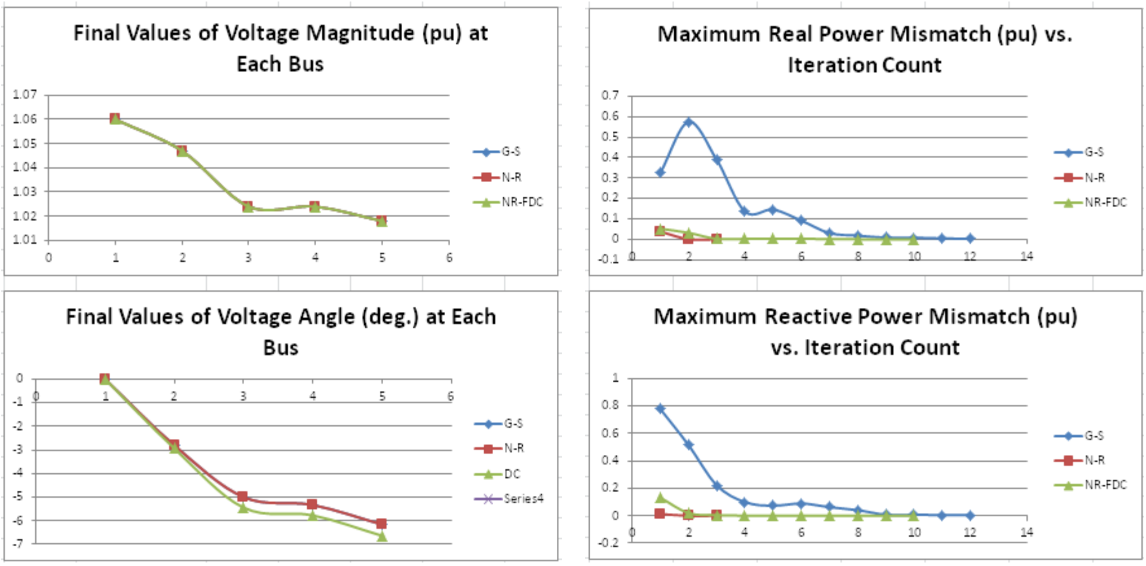

Figure 7. Comparison of LF algorithms for Stagg 5-bus system

Limitations and general observations

From the case studies and also from sample networks provided, it can be seen that the version 2 is as versatile as the previous version. However, it should be noted that this tool is not comprehensive enough to analyze complex system involving components such as HVDC links and power stabilizers etc. Though it is possible to use the tool, if those components can be modeled as line sections with additional buses, the regular load flow algorithms may have difficulty in converging. Most commercial applications switch the algorithms dynamically and make additional adjustments or assumptions during the iterations to achieve convergence.

This spreadsheet is designed to carry out off-line load flow studies without any adjustments. It is best suited for students who want to learn load flow studies, undertake comparative analysis, observe the response of the system under 'what if' conditions etc. Also, this tool provides an opportunity to the users to face situations when algorithms do not converge, which is part of the learning process. Larger networks with several control elements, ill-conditioned power systems, or systems with too many short lines with negligible reactances, or networks with high reactive power loading etc., pose challenges and users will experience difficulties with convergence (Gutierrez et al, (2011) and Amidaddin et al, (2012)).

According to IEEE(2015) standards the convergence limit can range from 0.1 to 0.0001 for systems with MVA base. The standard IEEE-57 bus fails to converge with a limit of 0.0001. If limit is changed (reduced) to 0.1 then convergence can be obtained. It should be noted that our spreadsheet comes with IEEE 57 bus data and the default convergence limit as 0.0001 and hence users need to change this value to 0.1 to obtain convergence. It is also possible to make a few changes to the network (increasing the impedance of the lines, removal of transformers etc.) for understanding reasons and factors for convergence.

Data accuracy and integrity of the spreadsheet are essential. It is observed that in a few instances, wrong values including zeros and negative values were used by users. And a few users have inserted (or deleted) one or two columns in the spreadsheets. Such unwarranted changes negatively impact the flow of the code execution and spreadsheet will not be able to perform as expected for obvious reasons.

6. Conclusion

Version 2 of the MSEBPSLF is developed based on user feedback and suggestions. From the sample networks and case studies, it can be seen that version 2 supports most requirements of classroom learning as two simple textbook based networks along with four standard IEEE networks have been provided. Re-design and simplification processes which are the essential parts of software management have been illustrated. Intermediate results provide more insights for the students in the learning process and even in experimenting with various conditions. Importantly, this version 2 has retained all the salient features from its previous version.

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