ASC: An open-source tool for Ancillary Support Estimation from Distribution network to Upstream Networks

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Abstract

This paper presents a Python-based tool designed for the network service providers to estimating frequency regulation and voltage support available from the distribution networks to the upstream networks. The tool includes a novel three-step time aggregation method to obtain representative profiles from historical time series data of loads, solar and wind generation, energy storage systems, and electric vehicles; check the security of the network for different loading conditions; and calculate available ancillary services supports- voltage and frequency regulations. The tool has been designed and validated with the network and data from an Australian Network Service Provider.

Keywords

Ancillary Service, DigSILENT PowerFactory, Frequency Support, Python, Spatial and Temporal Aggregation, TSO-DSO Interaction and Voltage Support

Code Metadata

Code metadata description	***Metadata***
Current code version	*V1.0*
Permanent link to code/repository used for this code version	*nhattan214/ASC: Ancillary Service Calculator*
Permanent link to reproducible capsule	*nhattan214/ASC: Ancillary Service Calculator*
Legal code license	*MIT License*
Code versioning system used	*git*
Software code languages, tools and services used	*Python 3.11*
Compilation requirements, operating environments and dependencies	*N/A*
Support email for questions	tan.pham@federation.edu.au, b.amin@federation.edu.au

Software Metadata

Software metadata description	***Metadata***
Current software version	*V1.0*
Permanent link to executables of this version	*https://drive.google.com/drive/folders/10aGcdbepoy_cADPQagk7M3WdE_hLGtUv?usp=drive_link*
Permanent link to reproducible capsule	*https://drive.google.com/drive/folders/10aGcdbepoy_cADPQagk7M3WdE_hLGtUv?usp=drive_link*
Legal software license	*MIT License*
Computing platforms/Operating Systems	*Windows*
Installation requirements & dependencies	*N/A. The software is portable*
Support email for questions	tan.pham@federation.edu.au, b.amin@federation.edu.au

1. Motivation and significance

The Electricity Network Transformation Roadmap projects that by 2050, Distributed Energy Resources (DERs) will account for approximately 45% of Australia's electricity generation capacity[1]. While DERs offer numerous benefits, their widespread adoption may also lead to challenges and technical issues, including network congestion and voltage excursions. To facilitate the integration of Renewable Energy Sources (RESs) without requiring substantial investments in new network infrastructure, the flexibility of managing connected (front of meter) DERs within the distribution network should be leveraged. Achieving this goal will require enhanced collaboration between Transmission System Operators (TSOs) and Distribution System Operators (DSOs). Additionally, it is important to explore how DERs can provide energy and ancillary services to the transmission network without compromising the stability of the power system.

In recent years, the energy sector has increasingly prioritized sustainable electricity production, with a particular focus on incorporating renewable energy sources (RESs) into distribution networks [1-3] [. However, implementing control modules to manage the variable output of RESs in these systems is expensive. To address this, planning policies that revolve around the cooperation between transmission networks (TNs) and active distribution networks (ADNs) facilitate more efficient RES integration [4, 5]. This approach reduces the reliance on costly equipment and lowers the operational costs of distribution systems [6, 7]. Transmission system operators (TSOs) are tasked with services such as voltage and frequency regulation, as well as congestion management at the transmission level. Meanwhile, distribution system operators (DSOs) are responsible for handling voltage and congestion within distribution grids [8]. When TSOs and DSOs coordinate effectively, they can fulfil their respective responsibilities while enhancing the stability, reliability, and security of the combined TN/ADN infrastructure. The function of

DSOs is still emerging and varies across regions. Currently, distribution network service providers (DNSPs), acting as distribution network operators (DNOs), manage local congestion and voltage issues. However, they typically do not take a system-level approach—meaning they do not actively regulate network inputs, outputs, or configurations to meet wider market or system objectives.

Although the increasing installation of DERs poses several operational and planning complexities in TS and DS, the interaction between TSO-DSO has the potential to provide flexibility and ancillary services to the network. Consequently, there is a need for a tool which can estimate the ancillary services to the network. In the current literature, there are existing Python-based, open-source libraries and software on power system modelling and optimization, such as PyPSA, Pandapower [9, 10]. However, they do not directly support the calculation of ancillary services, and they require modelling and coding skills to be used. To the best of our knowledge, there is no open-source, user-friendly tool to estimate frequency regulation and voltage support available from the distribution networks to the upstream networks. To this end, we introduce our Python-based, open-source *Ancillary Support Calculator* (ASC). The main contributions and features of this tool are as follows: 1) The ASC utilizes a novel three-step time aggregation method, considering both spatial and temporal aggregation of the network, to obtain representative profiles of loads, solar and wind generation, energy storage systems, and electric vehicles based on their corresponding historical time series. 2) The ASC is also capable of checking the security measures such as under/over voltage violations and overloading of the network by connecting with DigSILENT PowerFactory. 3) The ASC helps users to estimate the amount of frequency and reactive power ancillary supports from the distribution network to the upstream network using time aggregated profiles of the demand, DERs, ESSs and EV charging stations. Moreover, the tool comes with a friendly user interface, users can use the tool easily without the need of scripting skills.

2. Software description

The ASC is designed as a portable, Python-based desktop application. A user interface for the tool is developed with PyQt5 [11-13] . Data handling process is developed with the help of pandas library. The scikit-learn library is also utilized to develop the three-step time aggregation method, and Matplotlib is used for creating plots. The main features as well as the overall process of the ASC is described in Fig. 1. In the following subsections, we present the details of the components of the software, as well as the underlying three-step time aggregation method.

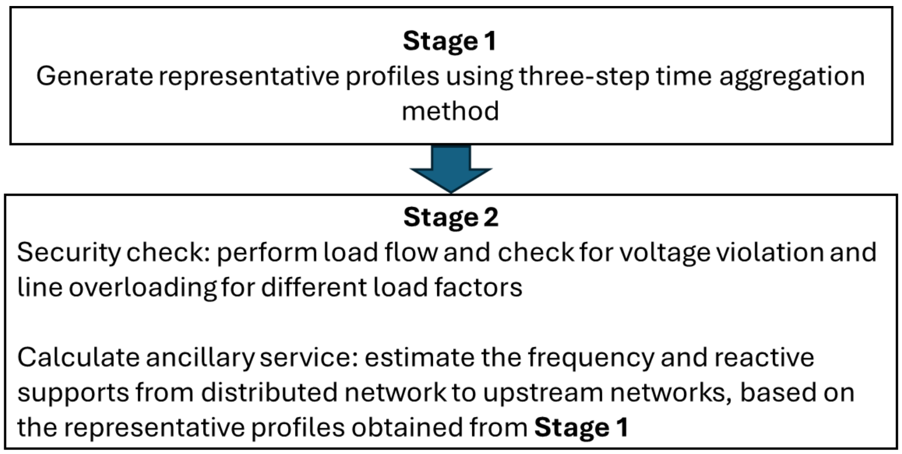

Fig. 1. Overall flowchart of the tool

2.1. Three-step time aggregation method:

We first present the development of the three-step time aggregation method. The K-means clustering algorithm is adopted to obtain time-aggregated clusters because it is a computationally efficient and effective clustering method widely used in power system studies. To determine the optimal number of clusters in the load data is obtained using the Silhouette criterion. The Silhouette method, established by Belgian statistician Peter Rousseau in 1987, offers a concise means of interpreting and validating the consistency within data clusters [14]. It presents a graphical overview of how effectively each sample has been classified. The Silhouette criterion can be defined as in (5)-(7) [14]:

$$S(u) = \frac{1}{n}\sum_{i=1}^{n} \frac{b\left(\frac{i}{u}\right)-a\left(\frac{i}{u}\right)}{\max\left\{b\left(\frac{i}{u}\right),a\left(\frac{i}{u}\right)\right\}},\ S(u) \in [-1,1] \quad (1)$$

where the indices i and u count the samples and clusters, respectively n indicates the number of samples in the dataset, n_{P_i} and n_{P_s} represent the number of samples in clusters P_i and P_s, respectively, d_{ik} is the Euclidean distance between samples i and k , d_{iP_s} is the Euclidean distance between sample i and cluster P_s, $a\left(\frac{i}{u}\right)$ and $b\left(\frac{i}{u}\right)$represent the distance of sample i with its assigned cluster (i.e., P_i) and minimum distance of sample i with other clusters upon the condition that there are u number of clusters, $S(u)$ is the value of the Silhouette criterion for the u number of clusters. The Silhouette value, ranging from -1 to +1, serves as a metric to gauge the similarity of a sample to its assigned cluster compared to the neighbouring clusters. A high Silhouette criterion value indicates strong cohesion within the sample's cluster and significant separation from neighbouring clusters, signifying a suitable clustering configuration. Conversely, a low or negative Silhouette value suggests potential issues with the clustering configuration, such as an inadequate number of clusters.

The three-step time aggregation can be summarized as follows. In the first step, one time series is obtained by calculating the centroid of all data sources. If any of the data sources contain negative values (i.e., energy export value), a shift transformation of that specific data series is performed using the maximum absolute negative value in the dataset. Let the dataset with negative values be y=f(x) and the maximum absolute value of negative values is c. Therefore, the dataset after shift transformation will be ynew=f(x)+c. In the second step, the K-means clustering method is used to obtain representative clusters of the centroid time series obtained from the first step. The maximum number of clusters is obtained using the Silhouette criterion. In the third step, reverse calculations for each data source are performed using the average participation factors of data sources in the centroid time series obtained from the first step. The maximum absolute value of the negative number will be subtracted from the representative profiles of the dataset that had negative values.

2.2. Software functionalities*:*

The main interface of the ASC is presented in two separate stages, as in Fig. 2. In Stage 1, the user need to provide the address to an Excel file containing the data file with a simple format, as in Fig. 3**.** The tool is capable to work with any time resolution data. However, in our study, the resolution of time series is half-hour. Thus, we have used complete 48 instances of selected days. All time series profiles should have the same number of instances. The 'plot' button is used to plot all the time series – Demand, PV, Wind and EV. The 'calculate optimal number of clusters' button identifies the optimal cluster number using Silhouette criteria. The 'Generate Representative Profiles' is to generate representative profiles. Finally, the 'Save' saves representative profiles in Excel file format. The files will be saved in the same folder where the tool is. The representative profiles are also saved internally to be used in Stage 2. For Stage 2, the user needs to use the "Browse" button to navigate to PowerFactory's Python API, for the security checking. The network security for all representative snapshots will be performed and the results will be saved in Excel files to the same directory. If there is any security violation i.e., bus over/under voltage, and/or line overloading, the number of violations will be counted in the Excel file. If the user still wants to proceed with the ancillary service estimation, he/she should complete the settings and click the 'Calculate' button. The main settings for this stage are described as follows:

- The percentage of total customers willing to participate in demand response
  - Mention the percentage of the total customers willing to participate in demand response, i.e., 40% of the total customers.
- The percentage of average participation of loads from each customer
  - This value is the average load participation from each customer to demand response, i.e., 30% of the load from each DR participant customer.
- The percentage of up and down reserve from the total DR reserve
  - 100% up and down reserve means that 100% of DR loads will be used for AS. The user can vary this amount to retain the network security.
- The average participation from PV owners
  - This value is the amount of AS committed to DNSP from the PV owner, i.e., 30%.
- The percentage of up and down reserve from the total PV reserve
  - 100% up and down reserve means that 100% of the PV reserve will be used for AS. The owner/regulator can vary this amount to retain the network security.
- The average participation from Wind owners
  - This value is the amount of AS committed to DNSP from the Wind owner, i.e., 30%.
- The percentage of up and down reserve from the total Wind reserve

- 100% up and down reserve means that 100% of Wind reserve will be used for AS. The owner/regulator can vary this amount to retain the network security.

- The average participation from EV stations
  - This value is the amount of AS committed to DNSP from the EV stations, i.e., 10%.
- The percentage of up and down reserve from the total EV stations reserve
  - 100% up and down reserve means that 100% of EV station storage will be used for AS. The owner/regulator can vary this amount to retain the network security.
- Percentage of ESS capacity for ancillary service
  - This is the amount of energy storage reserve for ancillary service. The other amount can be dedicated to reliability or other commitments, i.e., 50%.
  - The owner/regulator can vary this amount to retain the network security or save the battery life cycle.

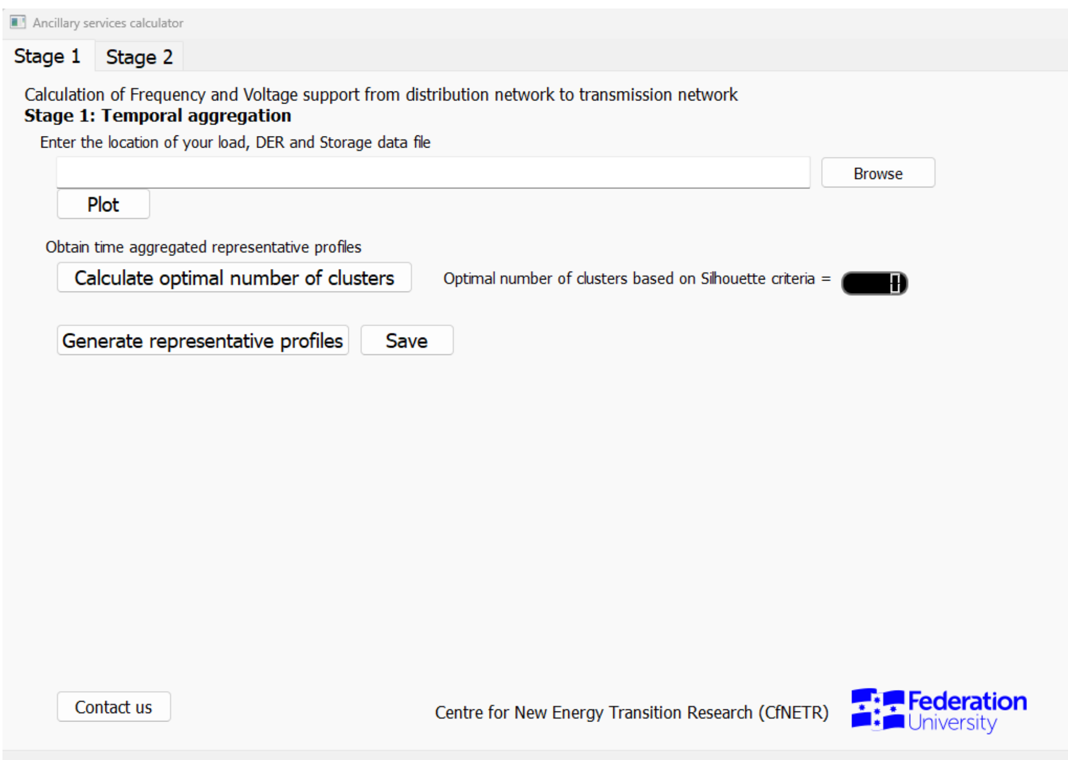

Fig 2a. ASC interface (Stage 1)

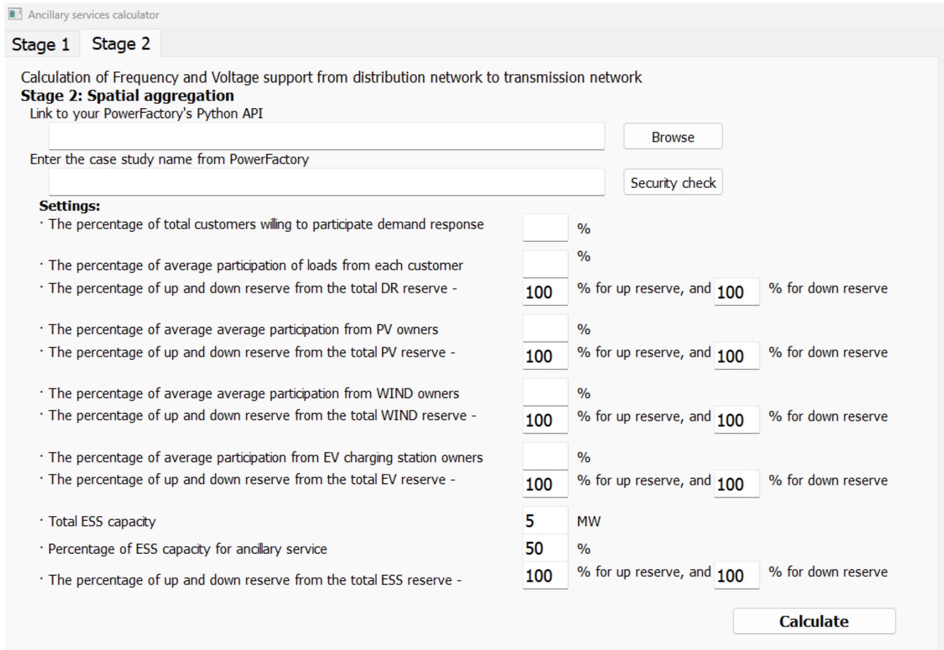

Fig 2b. ASC interface (Stage 2)

Demand - 2035	PV	Wind	EV
15.11	0.00	2.50	0.684552996
15.11	0.00	2.73	0.529624352
14.66	0.00	3.11	0.530403106
13.09	0.00	3.49	0.646004707
11.76	0.00	3.82	0.528787914
11.55	0.00	4.15	0.379714342
10.83	0.00	4.38	0.271626268
10.08	0.00	4.62	0.233222193
9.70	0.00	4.71	0.232602074
9.61	0.00	4.81	0.232270383
9.80	0.00	4.80	0.214272529

Fig 3. Excel format

3. Illustrative examples

The developed software has been tested using an Australian Network with front-of-the-meter DERs and storage connected to it. Three cases have been considered for ancillary service calculation – 1. With only demand response; 2. With demand response and DERs and 3. With demand response, DERs and storage.

At first, in stage 1, the time series data of demand, solar PV and wind generation and EV charging station are collected and formatted as the recommended excel file format for the software tool. The time series profiles are plotted using the software as illustrated in Fig. 4,5,6 and 7. The optimal number of clusters are found 2. Therefore, there will be two representative days profiles that will be used to calculate the ancillary services using the stage 2 of the software. The representative profiles are saved as excel file for future use.

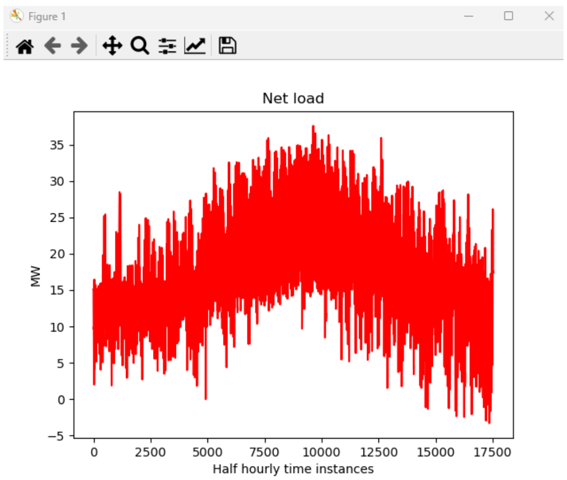

Fig 4. Yearly net load profile of an Australian Network.

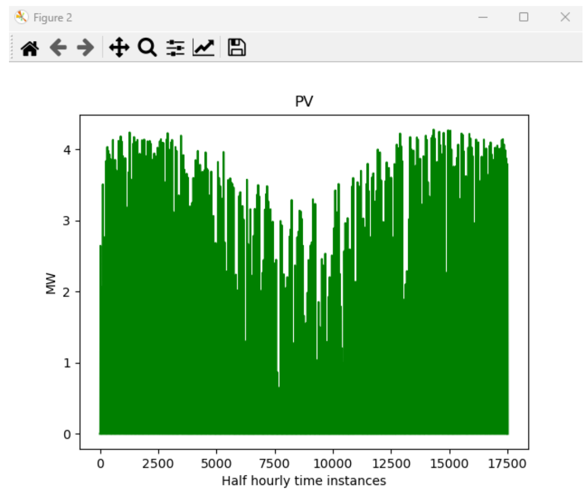

Fig 5. Yearly PV profile.

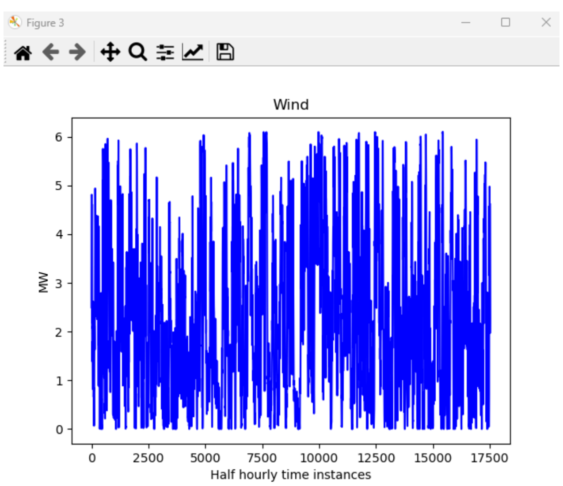

Fig 6. Yearly wind energy profile.

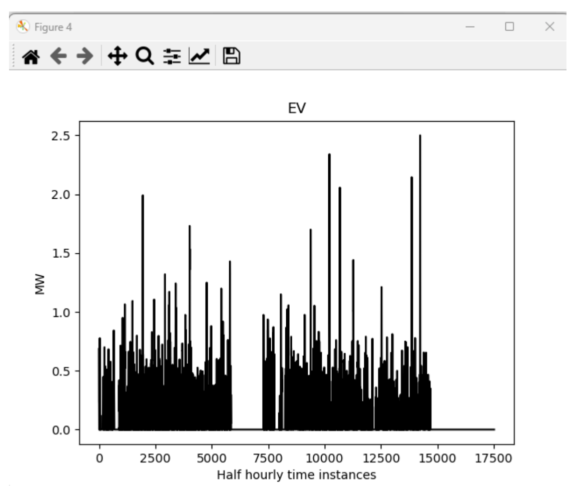

Fig 7. Yearly wind energy profile.

Secondly, in stage 2, the DIgSILENT file of the network is linked with the network for security check. In the security check section, mainly, the over and under voltage violations in the network nodes and overloading of the branch flow is measures and analysed. If any violation is found the software will provide a flag for that and the operator will be aware of this issue. There was no security violation in the network used for this example. The security has been performed for all instances of the representative days. Now, an example scenario has been considered and following settings are set for ancillary service calculation as illustrated in Fig.8.

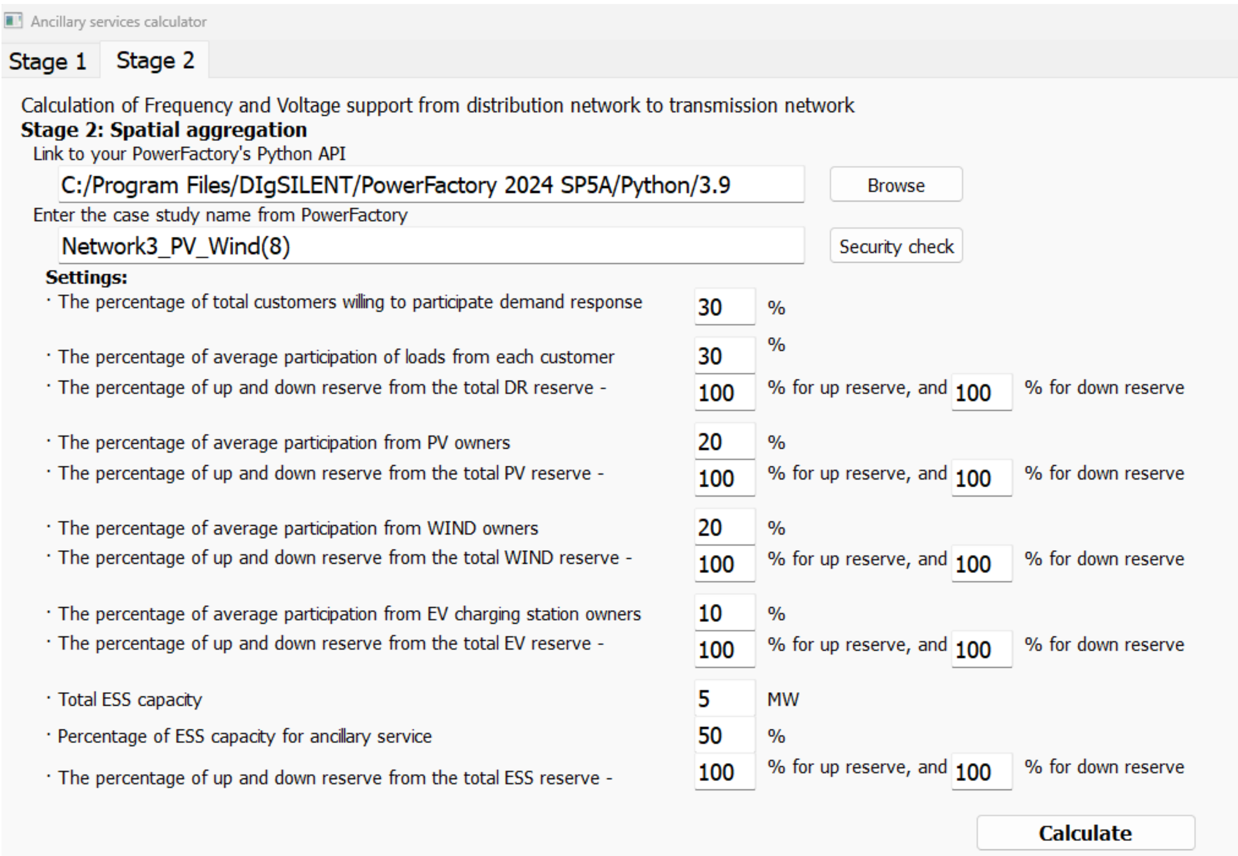

Fig 8. Settings used in the illustrative example.

The results for all three cases for all instances (96 for 2 representative days) are saved in three separate excel files. The network operator can analyse this estimation of ancillary services for operation and planning purposes.

4. Impact

Transmission and distribution networks are physically connected (from the circuit theory point of view, they are essentially one circuit). Thus, to run power system operation planning functions, such as SCUC, we need to consider transmission and distribution networks. However, incorporating distribution networks into a transmission system can easily make this operation planning functions intractable due to the large size of distribution networks, which can easily reach hundreds or even thousands of buses. Our proposed methodology can replace a very large distribution network in the range of hundreds or thousands of buses with an equivalent network in the range of 3-5 buses to make power system operation and operation planning functions, considering both transmission and distribution networks, tractable. This is a key advantage for both transmission-level stakeholders, like AEMO, and national network service providers.

For power system planning, the problem of scalability and the problem of tractability become even more critical and complicated. In addition to the operation problems, the developed methodology can be used for power system planning purposes.

5. Conclusions

The ASC is a free, open-source, user friendly tools to be used in tandem with PowerFactory, which is a common power system analysis and modelling software. The ASC aims to help researchers in both academia and industry to have a free tool for estimating available ancillary services supports-voltage and frequency regulations. The tool's source codes can be easily modified according to various standards, such as the resolution of input time series. For future versions, we aim to develop suitable application programming interfaces so that the ASC can be used with other free power system analysis tools, such as MATPOWER or Pandapower.

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