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Optimal Placement of Renewables and Storage for Distribution Level Network Stability

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Abstract— Stability of the grid network is given priority by power system operators and other key energy stakeholders, with growing interest in renewables, then the fact is that stability has become the cornerstone for grid power transaction. In this study, grid network topology is designed using pandas power library, and distributed energy resources (DERS) such as PV, Wind Turbine, and energy storage systems (ESSs) are added to various nodes. Subsequently, studies are carried out to assess voltage deviations, which entails performing optimal power flow simulations, whereby IEEE 33-bus network is used as a testbed. According to industrial standards, especially IEEE 1547 standard, deviation of voltage is specified at an interval, i.e., minimum voltage and maximum voltage which are noted to be 0.90 and 1.00 pu, respectively, this aligns with requirements of having DERs in the grid network. To maintain this interval, stability of the grid becomes a deeply researched topic of interest for many researchers and engineers. Particularly, in this work a 33-bus benchmark is developed using pandas power, heatmaps and analyzable cases are formulated in modeling the grid network. The developed cases exemplary capture power system simulation studies using pandas power. Run OPF function is actualized, and results are gotten for grid stability analysis. The impact renewables have on the grid has been attested to, with ESSs coming in handy to support voltage profile.

Keywords: Optimal power flow, pandas power, distributed generation, renewables, energy storage systems.

I. INTRODUCTION

The need to have robust and efficient power systems that are scalable and stable has pushed researchers to come up with better performing techniques, these techniques have facilitated energy transitional pathways which are discussed in [1], the frontiers in energy modelling have been pushed, not only with emergency of new technologies but also towards frameworks that are capable of representing the interdependencies between policy making, energy efficiency and infrastructure expansion, also market behavior of participants , environmental effects and finally security of supply.

These pathways are aimed at a cleaner energy transition, whereby interdisciplinary dependencies have to be considered, with the following steps becoming crucial in adoption of a cleaner energy distribution networks. Energy infrastructure, constitutes generation, transmission and distribution structures that physically deliver energy to the end consumer. Also, in consideration is environmental impact, as it is well known, fossil-based energy resources have for the longest time impacted the environment in a negative way, largely through release of carbon emissions, which has led to global warming, another critical component is policy making, which involves consultation process with policy makers, who ensure certain aspects of the whole system-infrastructure are not violated, and in that minimal performance criteria is achieved by all the stakeholders, i.e., adoption of renewable energy sources to contribute to the energy mix of fossil-reliant industries, this can be achieved by carrying out promotion campaigns to encourage use of renewable energy sources in firms and institutions ,i.e., PV and Wind. As mentioned, policy is at the heart of the energy transition process, and efficient policies have to be given weight, so as to ensure security of supply is guaranteed, with this in mind demand and supply forces have to be in equilibrium for a stable power system. It is imperative to mention market behavior, a very significant element that is very integral to energy distribution systems, the component has to be clearly understood by the participating parties and how they can intelligently place bids for maximum social welfare without jeopardizing the security of supply. Having highlighted the transition pathways, one of the critical pathways that cannot be overlooked is security of supply, which massively plays a role in terms of optimal performance of the grid network, whereby voltage magnitudes, line loading, real and reactive power have to be specified in advance to avoid system shutdown. The complexity of determining optimal conditions for a power system to operate is formulated as optimal power flow (OPF) problem.

OPF as a tool was first introduced in the early 1960s [2-3], and the terminology was first introduced by Dommel and Tinney in 1968 [4], originally the first OPF was structured as a economic dispatch problem, in which a single equality constraint is obtained and represents a power network system, with subsequent studies OPF is not only associated with economic dispatch problem but also a wide range of optimization problems that are related to power system studies. Over time, OPF has evolved, and market deregulation is one such factor that has facilitated grid power dynamics, which brings us to an important aspect, that is OPF objective is to obtain optimal settings that ensure safe operation of a grid network system, adherence to power flow equations, security operation of the system in place and operational limits of distributed generations (DGs).

So, the main challenge associated with OPF problem is dealing with continuous and discrete variables, the former is related to power outputs and voltage, while the latter is common in transformer tap settings, phase angles and injection of reactive power, discrete variables complicate the problem solution and can result in non-convex optimization problem. Research has shown significant progress in solving OPF-related problems, as there are quite a number of mathematical approaches that have been applied , linear programming (LP) has been extensively applied, the approach has its objective function and constraints in linear form with presence of decision variables, also non-linear programming (NLP) approach has also gotten attention, in this form, either the objective function or the constraints can be in non-linear form, lastly mixed integer linear and non-linear programming (MILP) or mixed integer non-linear programming (MINP), with this approach decision variables are both discrete and continuous, respectively. Ref [5- 6], lists conventional methods that have been developed to tackle OPF problem, with most popular methods being LP, sequential quadratic programming (SQP), generalized reduced gradient method (GRM) and newton method. Despite the methods having great performance, they solely depend on the initial guesses, mathematical nature of the OPF problem or the type of the optimization problem at hand, and lastly theoretical assumptions., convexity, differentiability, and continuity. In [7], advanced intelligence and computational techniques have been mentioned and have attracted researchers and power system engineers.

Further in [7], some of the most commonly used control variables that have to be adhered to have been mentioned they include, amount of real and reactive power outputs from generators, transformer settings, capacitors and reactors, phase angles and sizing for expansion planning and lastly, FACTS devices that require sizing for expansion planning, for instance in [8], an optimal placement and sizing problem has been studied, the authors have proposed Chu-Beasley genetic algorithm to determine optimal location of distribution static compensators (D-STATCOM). Additionally, the authors in [9], apply differential algorithm (DE), to optimally locate unified power quality conditioner (UPQC) in grid the network. The approach ensures mitigation of power quality setbacks by ensuring improved voltage and current profiles. Also, DE is compared with other existing algorithms, it was found out DE has a better convergence than genetic algorithm (GA) and immune algorithms (IA), equally in [9-10], FACTS devices in modern grid networks are known to provide voltage support functionalities that have emerged attractive in power systems.

which is undoubtedly in line with smart-grid concept that has been developed in [11], the aim is to integrate more distributed generations into the grid, for instance storage systems are proposed and given emphasis as they support grid flexibility during islanding operations, with the research implementing a sizing algorithm that is used to obtain an optimal number of storage units that can effectively counter contingencies that emerge in the distribution network. In [12], real and reactive power, voltage magnitudes and line loading have been considered for optimal location and sizing of DGs, in the meantime, renewable DGs have been given preference such as Wind and PV, they have been placed at specific busses to monitor the impact they might possibly have on the general power system, the algorithm of interest is GA. Further in [13], smart-grid systems of the future that incorporate vehicle to grid (V2G) platforms have been discussed, such platforms will aid in the move toward carbon neutral economy with electrification of vehicles becoming top priority. A number of literature sources have addressed optimal location of DERs, whereby reliability studies have been carried out by adding DGs units and circuits reclosers to reduce composite reliability index [13-14] , it was realized that addition of many reclosers led to low reliability index, and the overall cost of reclosers was also high compared to the reliability level to be achieved, presenting a tradeoff between cost and security of the overall system. Also, study in [16] aims at minimizing power losses using chaotic salp swarm algorithm with fuzzy logic decision-making. The algorithm optimally locates photovoltaic systems in a radial distribution system, with an objective of minimizing power losses, voltage deviation and boosting voltage stability index. The algorithm can further be applied to schedule energy storage systems for 24 hours. The results show better performance in allocation of photovoltaics and energy storage systems with an improved voltage profile that meets all the constraints in operation. Lastly, in [17] a two-point estimate method has been used by the authors to mitigate the uncertainties present in the OPF problem, which mainly covers competitive electricity markets. The uncertainties are as a result of market participants behaving in a manner that can jeopardize future interactions in the market space, and it is for this reason probability distributions of locational marginal prices (LMP) are calculated.

Fig. 1. Common OPF objective functions [7].

The remainder of this paper is as follows: Section II presents power system network design, section III optimal power flow, pandas power application for OPF solution is given in Section III, and Section IV gives the results and discussion of using IEEE 33 bus system model with heatmaps and voltage magnitude variations, and lastly in Section V the paper is concluded, and both future work and an acknowledgement is given.

II. POWER SYSTEM NETWORK DESIGN

Power flow or load flow is a widely used approach in power systems stability analysis, outputs from a power flow model include voltage at different buses, line flow connecting different buses and finally system losses. The outputs are usually obtained by solving nodal power balancing equation, these equations are usually non-linear and therefore iterating methods are usually a preferred choice, commonly used methods are, the Gauss-Seidel, Fast-decoupled and Newton-Raphson method which is a Newtonian method mentioned in [18], which has been derived using Jacobian matrix and similarly finds its application in radial distribution systems, the authors claimed the methods exhibits robustness similarly to back/forward sweep method. In the context of applying the methods for power flow solution, then the problem has to be approached as a linear problem using a DC power flow technique. Table 1, indicates slack, generation and load buses. Slack buses is used to indicate mismatches that exists between scheduled generation and total generation, also total system load with losses, it is also known as a reference bus as both voltage magnitude and angles are specified.

Table I. Specification of Real Power in Common Buses

Type of Bus	**Voltage** $(\lvert V_i \rvert \angle \delta_i)$		**Real Power**		
	Magnitude	**Angle**	**Generation**	**Load**	**Net real power**
Slack	Specified	Specified	Unknown	specified	unknown
PV	Specified	Unknown	Specified	specified	Specified
PQ	Unknown	Unknown	Specified	Specified	Specified

Table II. Specification of Reactive Power in Common Buses

Type of Bus	**Voltage** $(\lvert V_i \rvert \angle \delta_i)$		**Reactive Power**		
	Magnitude	**Angle**	**Generation**	**Load**	**Net reactive power**
Slack	Specified	Specified	Unknown	specified	unknown
PV	Specified	Unknown	Unknown	Specified	unknown
PQ	Unknown	Unknown	Specified	Specified	Specified

Also in Table 1, PV bus is indicated, it is also known as regulated or generator bus because of net real power being specified and voltage magnitude being regulated. Meanwhile, load buses are referred as PQ buses, both real and reactive power loads are specified, for PQ bus voltage magnitude and angles are unknown, while for PV only voltage angle is unknown [19]. In case of the slack bus, variables do not need to be solved since voltage magnitudes and angles are already specified. Finally, in determination of number of unknowns the following arrangement can be used, 2(n-1)(g-1), where n is the number of buses and g stands for the number of generators, when solving the unknowns real and reactive power balance equations have to be used, and this where admittance matrix come in, for these unknowns to be determined, admittance matrix has to be used.

Therefore, to understand power flow studies basic mathematical equations are important, they fully describe power flow studies that need to be carried out for safe operation of grid power networks. Admittance matrix is an important abstract model that has admittance values of lines and buses, the Y-bus square matrix has a dimension that is equal to the number of buses and its diagonal is symmetrical.

The values Y_{ii} are equal to the admittance connected to bus , while the non-diagonal entries are equivalent to the negative of the admittance that connects two buses i. and j, (2).

$$Y = \begin{bmatrix} Y_{11} & \cdots & Y_{1n} \\ \vdots & \ddots & \vdots \\ Y_{n1} & \cdots & Y_{nn} \end{bmatrix} \tag{1}$$

Large systems are usually represented using Y-bus as a sparse matrix[19],

$$Y_{ii} = \sum_{\substack{j=0 \\ j\neq i}}^{n} y_{ij} \tag{2}$$

$$Y_{ij} = Y_{ji} = -y_{ij} \tag{3}$$

Bus voltage V_i, can be used to calculate net injected power, also adjacent bus voltages V_j and admittances of two consecutive buses y_{ij}.

$$I_i = V_i y_{i0} + (V_i - V_1) y_{i1} + (V_i - V_2) y_{i2} + \cdots \tag{4}$$

Equation (4) can further be arranged to obtain (5) and (6), which is a function of voltages:

$$I_i = V_i\left(y_{i0} + y_{i1} + y_{i2} + .. + y_{ij}\right) - V_1 y_{i1} - V_2 y_{i2} - \tag{5}$$

$$I_i = V_i \sum_{\substack{j=0 \\ j\neq i}} y_{ij} - \sum_{\substack{j=1 \\ j\neq i}} y_{ij} V_j = V_i Y_{ii} + \sum_{\substack{j=1 \\ j\neq i}} Y_{ij} V_j \tag{6}$$

$$S_i = P_i + jQ_i = V_i I_i^* \tag{7}$$

$$S_i{}^* = P_i - jQ_i = V_i{}^* I_i \tag{8}$$

$$S_i^* = V_i^* \left(V_i \sum_{\substack{j=0 \\ j\neq i}} y_{ij} - \sum_{\substack{j=1 \\ j\neq i}} y_{ij} V_j \right) = V_i^* \left(V_i Y_{ii} + \sum_{\substack{j=1 \\ j\neq i}} Y_{ij} V_j \right) \tag{9}$$

Equation (7) and (8) represents power injected at a bus and net power injected at a bus, respectively. The current in (6) is substituted into (9) to obtain net injected power.

$$P_i = \mathrm{Re}\left\{ V_i^* \left(V_i Y_{ii} + \sum_{\substack{j=1 \\ j\neq i}} Y_{ij} V_j \right) \right\} \tag{10}$$

$$Q_i = -Im\left\{ V_i^* \left(V_i Y_{ii} + \sum_{\substack{j=1 \\ j\neq i}} Y_{ij} V_j \right) \right\} \tag{11}$$

Also, real and reactive power can be found using (10) and (11), which can be simplified into (12) and (13), respectively.

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| cos\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{12}$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| sin\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{13}$$

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{\substack{j=0 \\ j\neq i}} y_{ij} - \sum_{\substack{j=1 \\ j\neq i}} y_{ij} V_j = V_i Y_{ii} + \sum_{\substack{j=1 \\ j\neq i}} Y_{ij} V_j \tag{14}$$

And finally, current calculation can be written as a function of power, as shown by (14).

In carrying out load flow analysis or power flow studies, there are important analytical methods that can be used to get information pertaining to losses, loading of lines, reactive power flow, etc. The essence of such studies is to determine amount of power that can be generated, and the demand required or allocated at a particular node. In formulating an optimal solution, objective function and constraints must be clearly outlined to ensure smooth flow of power within the network. This could help in recognizing abrupt contingencies when they occur or when simulation of the grid network for stability analysis will be required. Regarding the secure operation of the grid system and expansion plans, there should be laid down assumptions, first a network boundary in terms of generation limits should be demarcated. Second, voltage should be within a given range, and lastly infinite combinations of generational units to meet demand at various nodes should be highly possible. After meeting these assumptions, a mathematical model has to be considered, which will entirely establish existing relationship between voltages and power in the grid, this is followed by numerical calculations that govern convergence and optimal determination of node voltages.

A. Problem Formulation

An optimization problem presents an objective function that is clearly defined while the constraints are set to ensure decision variables are within range, optimal sets are obtained when all system constraints are satisfied.

$$Min\ f(x, u) \tag{15}$$

Subject to: $$g(x, u) = 0 \tag{16}$$

$$Lmin \leq L(x, u) \leq Lmax \tag{17}$$

From. (16) to .(17), x represents a vector, which is a state variable of a power system, it contains the slack bus real power output (P_{p1}), also voltage magnitudes and phase angles of load buses are represented by V_{Lk} , and θ_{Lk} ,respectively. Meanwhile, generator reactive power outputs are noted as Q_p, and vector u is ideally for discrete and continuous decision variables, it contains set of real power generation P_{pN} and voltage magnitudes $|V_{pN}|$. On the other hand, transformer tap setting T_k and reactive power Q_{Ck}

are indicated (20).

$$u = [u_{\text{continuous}}, u_{\text{discrete}}] \quad (18)$$

$$u_{\text{continuous}} = [P_{p_2} \dots P_{p_N}, V_p \dots V_{p_N}] \quad (19)$$

$$u_{\text{discrete}} = [T_1 \dots T_N, Q_{C_1} \dots Q_{C_N}] \quad (20)$$

There are two types of constraints that need to be outlined in power flow problem, the first type are equality constraints, and the second type are the inequality constraints. The two types are mathematically represented below**:**

A. Equality Constraints

They include sets of power flow equations that are non-linear, which govern power systems during operation and expansion planning, (21) and (22).

$$P_{p_i} - P_{D_i} - P_{T_i}(V, \delta) = 0 \quad (21)$$

$$Q_{p_i} - Q_{D_i} - Q_{T_i}(V, \delta) = 0 \quad (22)$$

The equations above describe real and reactive power balance at bus , where P_{p_i} and Q_{p_i} are generated at bus i, respectively, the load demand P_{D_i} and Q_{D_i} are generated at the same bus i ,and finally T indicates total real and reactive power sent and received at bus i .

B. Inequality Constraints

These are the mathematical conditions that a power system has to meet in order to operate efficiently, they can either be discrete or continuous sets of conditions, also they specify the limits the system components have to meet, for instance they can limit amount of power transmitted or generated at a particular bus.

1. The amount of real and reactive power that generators can produce is limited as below:

$$P_{p_i}^{min} \leq P_{G_i} \leq P_{p_i}^{max}, \; i = 1, \dots, G_N \quad (23)$$

$$Q_{p_i}^{min} \leq Q_{p_i} \leq Q_{p_i}^{max}, \; i = 1, \dots, G_N \quad (24)$$

2. While voltages magnitudes at every bus in the network is limited using as below.

$$V_i^{min} \leq V_i \leq V_i^{max}, \; i = 1, \dots, N \quad (25)$$

3. Transformer tap settings which are discrete in nature.

$$T_i^{min} \leq T_i \leq T_i^{max}, \; i = 1, \dots, T_N \quad (26)$$

4. Capacitor banks accept discrete reactive injections and can be quantified the condition below.

$$Q_{C_i}^{min} \leq Q_{C_i} \leq Q_{C_i}^{max}, \; i = 1, \dots, C_N \quad (27)$$

It is important to note that, P_{p_i}, Q_{p_i}, and V_i can take any value within a given range(continuous), while T_i and Q_{C_i} only take specific values(discrete).

5. Also, transmission lines have maximum capacity loading specified, this guards the network from unexpected outages or damages as a result of overloading.

$$S_{L_i} \leq S_{L_i}^{max}, \; i = 1, \dots, L_N \quad (28)$$

Other inequality constraints include avoiding generation of power in areas or zones that are detrimental to power network systems, stability under external disturbances and finally level of electromagnetic interference.

III. PANDAS POWER APPLICATION FOR OPF SOLUTION

Pandas power a library used for power systems simulation is used, IEEE 33 bus system in this paper has been designed as standard testbed, buses, lines and transformer parameters are carefully chosen to ensure OPF algorithm converges.

Fig.2 shows the configuration state of IEEE 33 bus system, which is significantly used to optimally size DERs, in this regard, Wind Turbine and PV are contemplated into the network, 3 generators and one load unit are also included, for the purpose of continuous assessment of this network, cases are chosen on the basis of the nature of generation unit. There are a total of 6 main test cases, with the seventh case being an extension of the sixth case, whereby additional load of 10MW is introduced in bus 26. Fig.3 shows how voltage magnitudes and the extent of loading the lines beyond their rated capacity vary, the lines are shown using different colors to show cases when overloading occurs. The external grid is shown by the yellow spot and the green line represents the transformer that is between HV and LV buses, Fig.2.

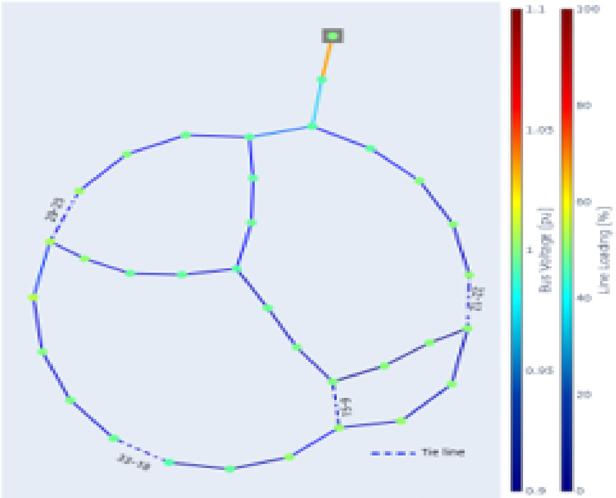

Fig. 2. IEEE 33 bus system network

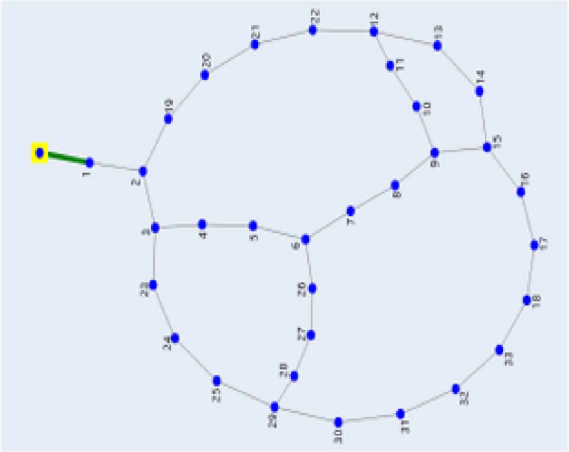

Fig. 3. IEEE bus system heatmap post-OPF analysis

Usually in a 33-bus system, lines are synchronously connected to indicate direction of power from bus 1 to bus 33, with tie lines representing switching from one zone to another, Fig.3. Also, the figure shows how critical lines can be identified, these are the lines that depict the effect of overloading, parameters for various lines are selected rated real and reactive power for these lines are given to enable convergence of OPF at the same time critically affected lines can be identified.

IV. RESULTS AND DISCUSSION

In the simulation of the grid, Wind power, PV and other DGs are considered, Base power of 20MVA is used, Substation voltage of 12.66kV, HV is 20kV, minimum and maximum voltage magnitude of 0.85 and 1.15 are specified, respectively. Three diesel generators of 0.6MW each are used and connected to bus 16,20 and 30. There is a PV and Wind Turbine attached to bus 18 and 27, respectively. Each of them has 2MW and 0.012MW, respectively. There are also two energy storage systems, the first storage system is connected to bus 26 and the second storage is connected to bus 28, the first storage node is analyzed by addition of a 10MW load to form a load and storage combination, which is formulated as case 7.

Case 1: Without renewables only storage and DGs.

Renewables have not been considered, two storage systems at bus 26 and 28 are simulated for OPF studies, Fig. 5, optimal performance of lines including transformer line is shown, the transformer is loaded at 46%, therefore based on the color shading the system is not overloaded and there are no critical issues to look after, voltage profile is within the margin, exactly 1 pu at maximum and 0.99 at minimum. This indicates that the grid is in optimal operation. When compared to case 2, case 1 is more stable than case 2, Fig.6. Case 1 and 2, are both shown in Fig. 4 and 5, respectively.

Case 2: With only DGs

In this case, only diesel generators are used, and still the power system has optimal performance, with a quick convergence rate of the OPF, voltage magnitude is within the specified limits, as shown in Fig.6. The transformer is operating at 51%, which is below the expected rate of above 65%, which ideally implies the system is operating at a steady state when voltage magnitude is observed.

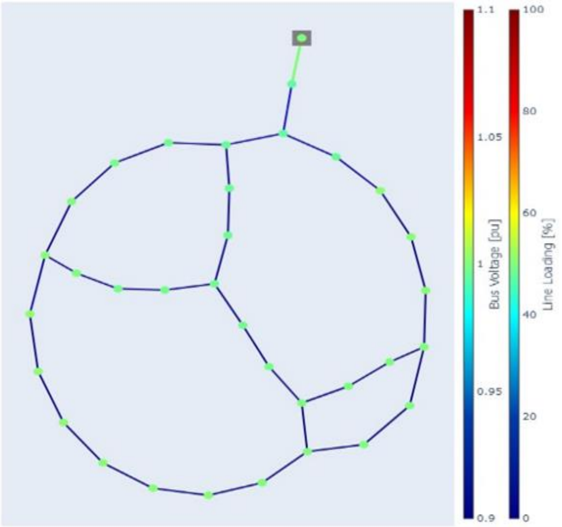

Fig. 4. Case 1 Without renewables only Storage and DGs.

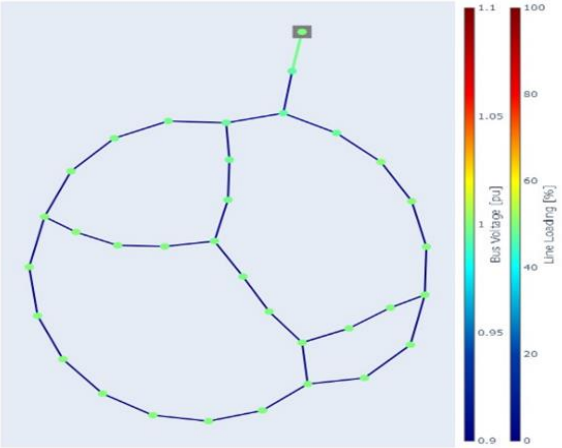

Fig. 5. Case 2 with only DGs.

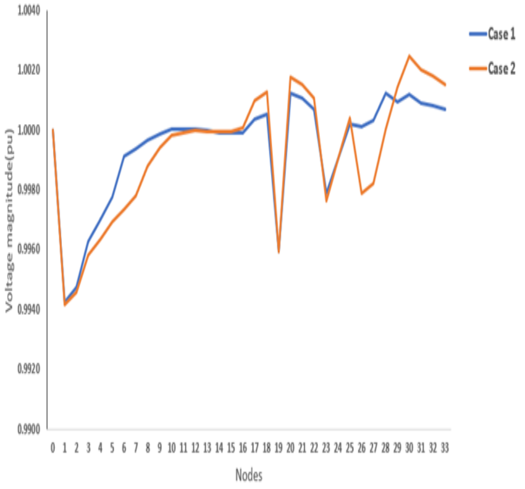

Fig. 6. Case 1 and case 2 voltage magnitude comparison.

Case 3 With PV, Wind and Storage

In case 3, the transformer operates at 59 %, as can be seen on the line connecting HV bus to LV bus, and on average the lines connecting different buses are loaded at 40%, as seen in Fig.7, inclusion of storage is a pure indication of how storage can support grid stability.

Case 4 With PV, Wind, DGs and without Storage

In this case, as shown in Fig.8, the transformer operates at 68%, which is normal, and the exception of storage in the IEEE-33 bus system can been seen.

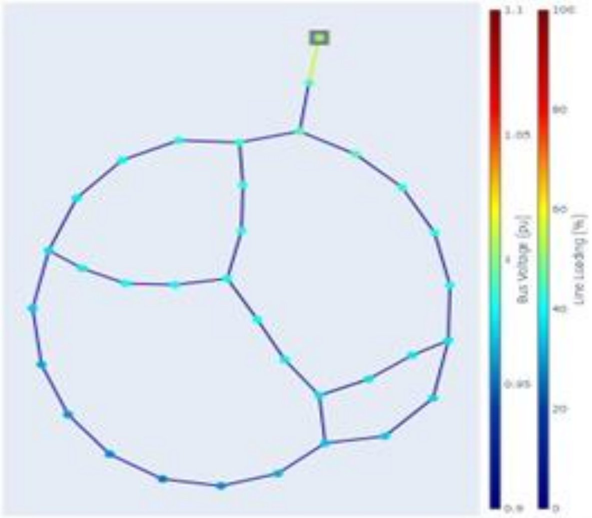

Fig. 7. Case 3 with PV, Wind and Storage

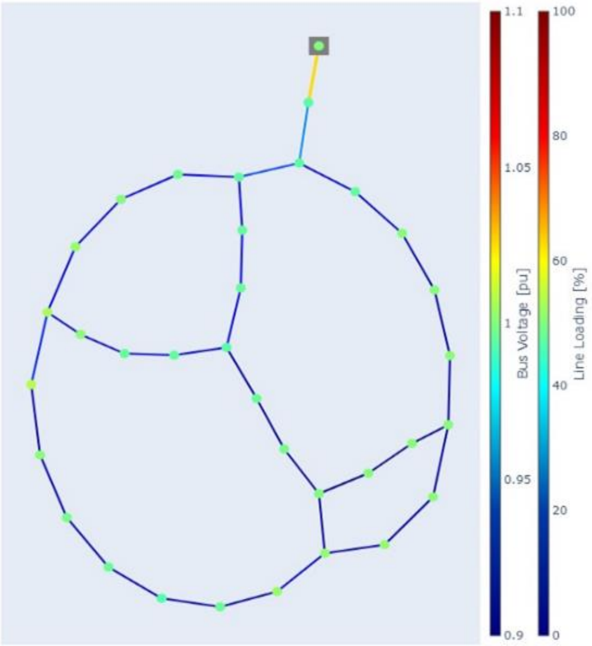

Fig. 8. Case 4 with PV, Wind, DGs and without Storage

Case 5: With PV, Storage and DGs

In case 5, the scenario when Storage is added and Wind is exempted is presented, the impact this arrangement has on the grid is indicated in Fig.9, with a steady voltage magnitude being an indication of optimal operation of the power system, and in this case the transformer is loaded at 64%.

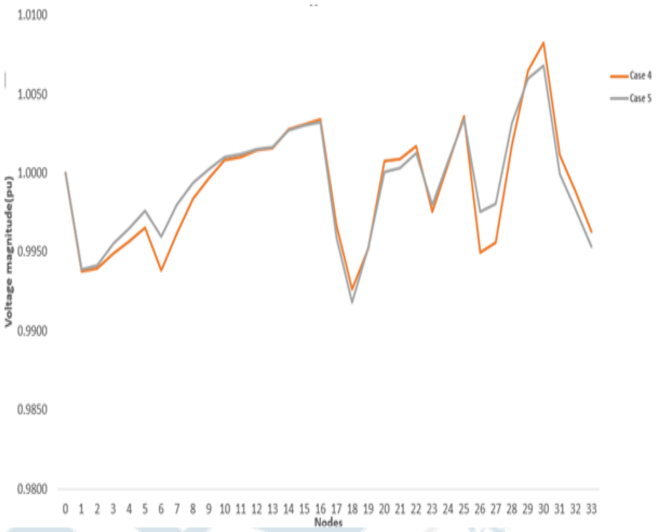

Fig. 9. Comparison of case 4 and case 5

Case 6: With PV, Wind, Storage and DGs

When Wind Turbine is included, there is not much of a difference in terms of loading of the transformer, and the transformer loading is still 64%, and both case 5 and case 6 have the same heatmap as shown in Fig.10.

Case 7: With PV, Wind, Storage and DGs with a 10MW added to bus 26

Varying of the load in power systems has immense effects as shown by Fig.11, which has a 10MW load added to bus 26, the transformer is loaded slightly more than 80%, which is very damaging and might result in transmission lines overload which in turn affects optimal performance of the whole system.

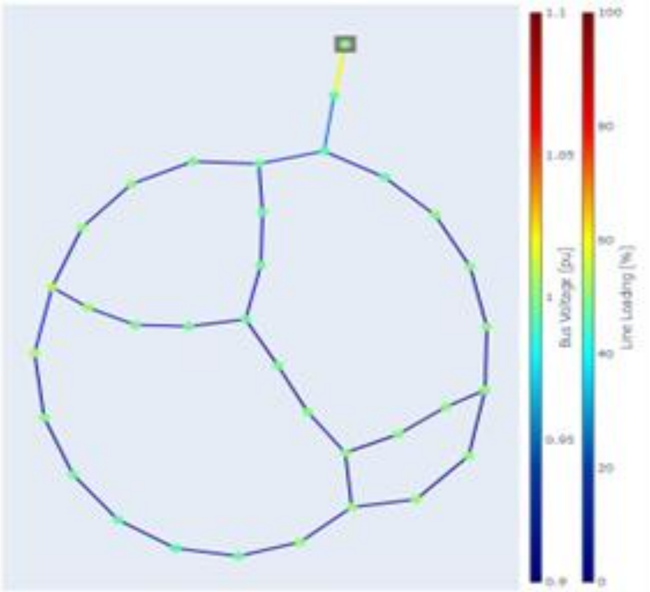

Fig. 10. Case 6 with PV, Wind, Storage and DGs

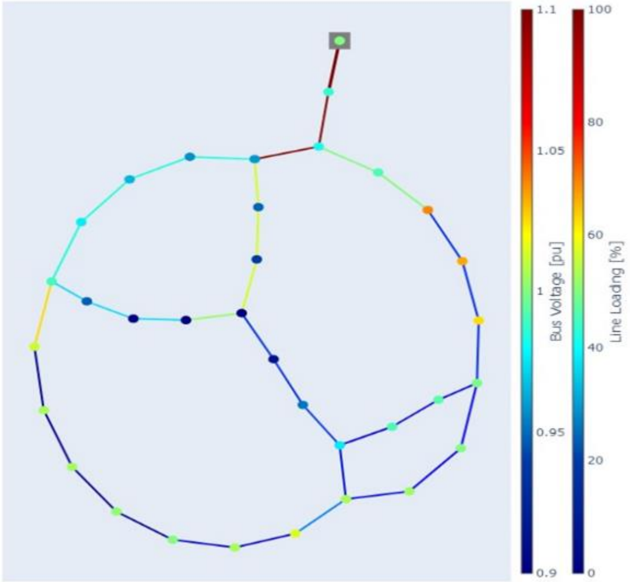

Fig. 11. Case 7 with PV, Wind, and DGs, extra 10MW load.

As shown in Fig.12, comparison of case 3, case 6 and case 7 indicate how voltage magnitude is disrupted, and it can significance changes in bus 26 can be implied, which experiences overloading.

Fig. 12. Comparison of case 3, case 6 and case 7.

Fig.12, clearly indicates that when we have only case 3, load and supply are fairly met, and the grid is on the safe operation, and power flow from bus 0 to bus 33 is within safe voltage margin, this guarantees safety of power components and control of intermittent resources, similarly in case 6, voltage magnitude is slightly within the expected range which is a measure of how stable the grid can be under the right proportion of renewables, storage and DGs. However, when this arrangement is adjusted by addition of 10MW load at bus 26, the resulting voltage profile violates the set minimum and maximum voltage limits. This can be noted as, placement of a 10MW load at bus 26 violates the security requirements of the grid, and therefore other nodes can be tried by changing the arrangement of generation units and positioning the loads on safe nodes. Other important aspect is role of storage in power systems and how effectively it can contribute to grid stability. Storage provides a lot of services to the grid, i.e., in distribution networks, services such as leveling of load, voltage support and relived operation of distribution network components are indispensable. Additionally, storage supports integration of renewables into the grid as seen in most of the cases that have been mentioned. The study done in [20], points to the significance of storage in power systems and existing categories, i.e., storage can be used to provide renewables capacity farming, which entails power smoothening by absorbing peaks and altering of valleys in generation.

Another aspect is incorporation of DGs, for example case 5. DGs contribute largely to steady power flow and improved voltage profiles across the nodes despite being fossil-based. As research progresses through combined efforts and studies, DGs percentage in grid penetration will be reduced to accommodate more renewables, at the same time the need to have a robust and adaptive grid network systems will be part of the grid network transformation agenda.

V. CONCLUSION

The main pillars of this paper have been discussed, with solution of OPF problem being a paramount topic, which has been there for quite a long time, the problem has been introduced and its significance in the energy transition pathways has been given. The pathways, involve a safe transition to a modern grid network, that has all the capabilities to handle various contingencies, and poses advanced flexibility functions, such as demand response and improved energy trading algorithms, forecasting modules, i.e., load and generation forecasts. Through the emergence of renewables and support programs for a green energy future, these generation systems will have to be optimally managed for a stable grid, which in turn raises complexity in terms of optimal location and sizing of these resources. Many studies have been done in this area, but in this specific work, effects of locating these resources in the power system has been focused on, and Pandas power has been used to generate heatmaps with different cases for comprehension purpose and visualization of power networks. The grid was designed directly in a code and not conventionally read from an excel file. The IEEE 33-bus system was found to be enough for this work, as a testbed its nodes, rated power capacities, bus types and transformer parameters were specifically chosen to perform power simulation studies.

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