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# Achieving AC Power Flow Convergence Through Generator Active Power Re-Dispatch

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**Abstract.** The importance of a converged AC power flow (ACPF) case cannot be overstated, as it forms the foundation of other power systems studies. However, achieving a converged power flow model can be particularly difficult due to the non-linear nature of the power flow equations. Convergence is further affected when excessive power flows through certain transmission lines causing significant overloads. This paper addresses this challenge by developing an algorithm that achieves ACPF convergence by re-dispatching the active power of selected generators to alleviate congestion on critical transmission lines, thus restoring the ACPF case to a solvable operating point. The algorithm performs the re-dispatch using the bus mismatch data from the initial diverged ACPF case and DC power flow based linear distribution factors. This method was implemented on the 6102-bus Electric Reliability Council of Texas (ERCOT) grid under multiple operating conditions and successfully facilitated the convergence of 64 cases out of 74 non-converging ACPF cases. Additionally, the voltage quality of the newly converged cases are analyzed.

**Key words.** AC Power Flow Convergence, Generator Redispatch, Distribution Factors, DC Power Flow, Transmission Line Congestion

## 1. Introduction

An accurate and well converged AC power flow (ACPF) model is essential for various power system studies, including stability analysis, generator interconnection, and reliability assessments [1] [2]. Power flow analysis provides insights into grid operations under different generation and load scenarios. The power flow solution yields key information for grid planners, such as transmission line loading, system losses, and voltage quality [3]. Several numerical techniques exist for solving ACPF, including iterative methods like Newton-Raphson and non-iterative methods such as DC power flow (DCPF) and holomorphic embedding. Among these, the Newton-Raphson method is widely used in industry due to its robustness and quadratic convergence properties [4]. However, achieving convergence with Newton-Raphson ACPF can be challenging, particularly in large-scale grids. Grid planners often invest significant time and effort in developing solvable power flow models, as many large-scale cases fail to converge, especially under peak load conditions. The increasing penetration of renewable energy further complicates convergence. In some scenarios, an ACPF case may even become unsolvable [5]. An ACPF case is said to be converged (or solved) when the power mismatch tolerance falls below a specified threshold - ideally zero, though in large models, a mismatch under 1 MW is generally acceptable. Power flow equations are complex, non-linear, and may have multiple solutions. Several factors influence their convergence.

The initial conditions play a crucial role in ACPF convergence. Iterative methods like Newton-Raphson are sensitive to the initial guesses of voltage magnitudes and angles. Although the solutions of the power flow equations are the bus voltage magnitude and angles, an initial guess of the voltage solutions (bus voltage magnitude and angles) is needed to solve the power flow equations. Research indicates that an initial guesses far from the region of convergence would cause the ACPF case to diverge [1]. Various researchers have developed analytical [6], homotopy and artificial intelligence-based techniques to attempt to solve the initial guess problem [7], [8], [9].
Non-convergence may also result from local reactive power issues. An ACPF case might fail to converge if there is insufficient reactive support to prevent voltage collapse at specific buses. To address this, researchers in [10] and [5] applied reactive power planning methods where fictitious generators with zero active power and unlimited reactive power are added to the power flow model. In addition to this, non-convergence can also occur as a result of improper control setting of tap-changing transformers and switched-shunt devices in the power flow model.

The operating conditions of loads and generators significantly impact power flow convergence. As established in [5], each bus has a maximum loading condition beyond which no power flow solution exists. Researchers at the Pacific Northwest National laboratory (PNNL) developed an algorithm to achieve ACPF convergence through load reduction [11]. Although this method is quite effective, load reduction is typically a last resort, as controlling generation is generally more practical. Furthermore, the active power generator dispatch can cause excessive amounts of power to flow through certain transmission lines. The overloads can cause the power flow case to diverge.

This paper addresses the convergence challenges in power flow models caused by the operating conditions of loads and generators. We introduce a method to redispatch the active power of existing generators to achieve convergence in previously non-converging AC power flow (ACPF) cases. By re-dispatching the generators, overloads on critical lines—which cause non-convergence—are alleviated, thereby restoring the solvability of the power flow case.

The existing literature contains limited research on achieving power flow convergence through generator re-dispatch. The prominent work in this field is from researchers in [12] where information from an intermediately solved ACPF case is used to re-dispatch generators connected to the line with the largest overload. In their methods, the active power of the generators at the sending end of the line is reduced while the power at the receiving end is increased. Although this method shows promise, the generators at the sending and receiving end may not necessarily be the most effective choices for re-dispatch. A more analytical way of selecting the generators to re-dispatch would enhance the efficiency of the solution method. Also, researchers in [12] did not consider the generator limits, and the effectiveness of their re-dispatch method was not tested on multiple operating conditions.

In this paper, we propose an algorithm to re-dispatch the active power of existing generators to achieve convergence in previously non-converging ACPF cases. The algorithm uses the active power bus mismatch of the last Newton-Raphson power flow iteration to identify the critical transmission line causing divergence. It then applies DCPF and linear distribution factors to determine which generators should be re-dispatched to restore the ACPF case to a convergent operating point.

The main contribution of this work compared to existing literature are as follows.

1) Identification of overloaded critical transmission lines causing divergence using the bus mismatch data of the last iteration of the diverged ACPF case.
2) Development of an automated algorithm to achieve ACPF convergence by re-dispatching generators sensitive to critical transmission lines using DCPF and linear distribution factors, while considering generator limits.

The proposed generator re-dispatch algorithm is applied to the 6102 bus Electric Reliability Council of Texas (ERCOT) grid, under various operating conditions.

## 2. Methodology

### *A. Generator Active Power Re-Dispatch Methodology*

The generator re-dispatch algorithm operates on the hypothesis that a power flow model diverges due to thermal overload on certain transmission lines. To alleviate this congestion, the algorithm adjusts the active power output of existing generators, thereby restoring the solvability of the ACPF case. The re-dispatch algorithm begins by identifying the congested transmission line responsible for the divergence. Then it determines the location (generator buses) where power must be injected or removed to relieve the congestion. Additionally, the algorithm calculates the exact amount of active power, $P_{req}$ , that needs to be added or removed at the selected generator buses. Using this information, the active power of these generators are adjusted accordingly, ensuring that while individual generator outputs may change, the total system-wide active power remains the same.

Fig. 1 gives an overview of the generator re-dispatch method. First full Newton Raphson power flow is performed on the case. If the ACPF case diverges then the active power bus mismatch from the last Newton Raphson iteration is used to identify the critical bus ($Bus_k$). The critical bus is essentially the bus with the largest active power mismatch. Next DCPF is performed on the case to get a solution (since DCPF does not diverge). Although this DCPF solution is not viable in ACPF it is used to find critical transmission lines and calculate the generator re-dispatch powers to alleviate the overload on the critical transmission lines, thus restoring the solvability of the ACPF case. From the DCPF solution the thermal loading of all transmission lines connected to $Bus_k$ are analyzed. The transmission line with the largest overload connected to $Bus_k$ is selected as the critical transmission line ($Line_{kj}$). Where $Line_{kj}$ is the line connecting $Bus_k$ to $Bus_j$. The extra overload flowing on the selected transmission is calculated using (1)

$$P_{over,kj} = \left|P_{flow,kj}\right| - P_{rating,kj} \tag{1}$$

where $P_{flow,kj}$ is the active power flowing on $Line_{kj}$, $P_{rating,kj}$ is the active power rating of $Line_{kj}$ and $P_{over,kj}$ is the overload on the line.

Once the critical transmission line and its overload have been identified, the re-dispatch algorithm selects the appropriate generator buses and determines the required power adjustments to eliminate the overload, ensuring that $P_{over,kj} \le 0$. Generator buses are selected using injection shift factors (ISF) and power transfer distribution factors (PTDF), as outlined in Algorithm 1. The new generator dispatch values obtained are then implemented in ACPF and full Newton Raphson power flow is performed on the case. If the case converges then it means the re-dispatch algorithm has successfully solved the ACPF case. If the case diverges, the algorithm iterates by identifying a new critical overloaded transmission line. If no further overloaded lines are found, it indicates that the divergence is not due to excessive thermal overload. This requires further analysis which is beyond the scope of this paper.

The entire process is automated using python and requires just the non-converging ACPF case as input.

### *B. Algorithm to Obtain Generator Re-Dispatch Values*

Algorithm 1 shows how the generator active powers are re-dispatched using linear distribution factors to ensure that $P_{over,kj} \le 0$. The $ISF$ is used to find the generators to redispatch and it is calculated relative to the slack bus. It represents the change in power flow on a transmission line resulting from a unit change in power injection at a specific bus. The $ISF$ of $Line_{kj}$ due to an additional 1 MW injection at $Bus_m$ is denoted as $\Psi_{kj}^{m}$. The $ISF$ is calculated using (2), where $\Delta P_{kj}^{m}$ represents the change in active power flow on $Line_{kj}$ and $\Delta P_m$ is the change in active power at generator $Bus_m$ as a result of the extra 1MW injection. Alternatively, $\Psi_{kj}^{m}$ can also be calculated using incident and admittance matrices.

$$\Psi_{kj}^{m} = \frac{\Delta P_{kj}^{m}}{\Delta P_m} \tag{2}$$

The ISF for all generator buses are calculated, and the buses with the most negative and most positive ISF values are selected for redispatch. For illustration, let the most negative $ISF$ be $\Psi_{kj}^{n}$ (at $Bus_n$) and the most positive $ISF$ be $\Psi_{kj}^{m}$ (at $Bus_m$). This indicates that increasing generator power at $Bus_n$ would reduce the power flow on $Line_{kj}$ and increasing the generator power at $Bus_m$ would increase the power flowing on $Line_{kj}$.

Essentially, this means that to reduce the overload on $Line_{kj}$, the active power of generators at $Bus_n$ needs to be increased and the active power of generators at $Bus_m$ needs to be reduced.

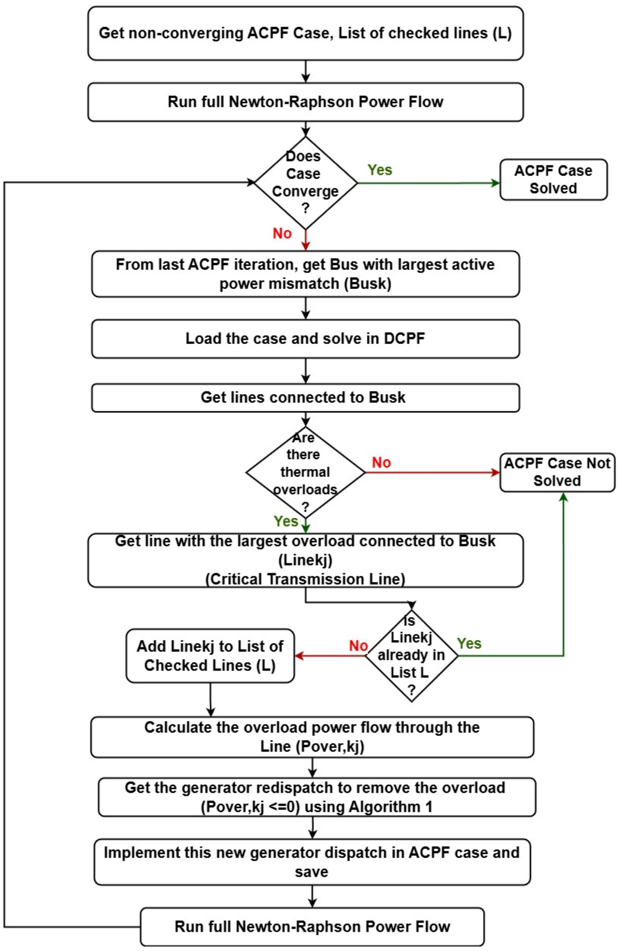


Fig. 1. Flowchart of the Generator Re-dispatch Method

**Algorithm 1: To Obtain Generator Active Power Re-dispatch Values**

**Calculate Injection Shift Factor** $ISF$ **for all generator buses**
**Calculate the extra overload branch flow** $P_{over,kj} = |P_{flow,kj}| - P_{rating,kj}$
**while** $P_{over,kj} > 0$ **do**
  **Select available generator bus pair (most negative ISF** $Bus_n$ $(\Psi_{kj}^{n})$ **and most positive ISF,** $Bus_m$ $(\Psi_{kj}^{m})$ **that reduces the flow on** $Line_{kj}$
  **Get** $P_{avial}$**, minimum available extra power on both** $Bus_m$ **and** $Bus_n$ **without exceeding limits**
  **Calculate the PTDF of the line kj** $PTDF_{kj}^{nm} = \Psi_{kj}^{n}$ - $\Psi_{kj}^{m}$
  **Calculate** $P_{req} = |P_{over,kj}/PTDF_{kj,nm}|$ **the required Power to add and remove from generators at** $Bus_n$ **and** $Bus_m$ **to reduce** $P_{over,kj} = 0$
  **if** $P_{req} > P_{avial}$ **then**
    **Add and remove** $P_{avial}$ **uniformly from generators at** $Bus_n$ **and** $Bus_m$ **respectively**
    **Calculate line flow reduction** $P_{red,kj} = |PTDF_{kj}^{nm} * P_{avial}|$
  **else**
    **Add and remove** $P_{req}$ **uniformly from generators at** $Bus_n$ **and** $Bus_m$ **respectively**
    **Calculate line flow reduction** $P_{red,kj} = |PTDF_{kj}^{nm} * P_{req}|$
  **Update the generator active power dispatch at** $Bus_n$ **and** $Bus_m$
  **Update** $P_{over,kj} = P_{over,kj(t-1)} - P_{red,kj}$
**Save generator dispatch values for ACPF Implementation**
**End**

The minimum available power that can be added or removed from generators at $Bus_n$ and $Bus_m$ is obtained and denoted as $P_{avail}$.

After identifying the generators to redispatch, the required power to be added or removed from the selected generators is calculated using the $PTDF$. The $PTDF$ of $Line_{kj}$ between $Bus_n$ and $Bus_m$ is denoted as $PTDF_{kj}^{nm}$ and it shows the change in power flowing on a line due to power transfer between two buses. In other words, if 1MW is added at $Bus_n$ and simultaneously removed from $Bus_m$, the resulting change in the flow on $Line_{kj}$ is the $PTDF$. $PTDF_{kj}^{nm}$ is calculated as the difference between $\Psi_{kj}^{n}$ and $\Psi_{kj}^{m}$ as shown in (3).

$$PTDF_{kj}^{nm} = \Psi_{kj}^{n} - \Psi_{kj}^{m} \tag{3}$$

Using the $PTDF$, the required power $P_{req}$ to be added and removed from the selected generators are calculated as shown in (4).

$$P_{req} = \left| \frac{P_{over,kj}}{PTDF_{kj}^{nm}} \right| \tag{4}$$

If $P_{req}$ is less than or equal to the available power $P_{avail}$ of the generators at both $Bus_n$ and $Bus_m$, then $P_{req}$ is added to generator $Bus_n$ and $P_{req}$ is removed from generators at $Bus_m$. The new dispatch values of the selected generators are then saved. This re-dispatch based on $P_{req}$ would reduce the flow on $Line_{kj}$ by $P_{red,kj}$. The value of this reduction is calculated using (5).

$$P_{red,kj} = \left| PTDF_{kj}^{nm} * P_{req} \right| \tag{5}$$

However, if $P_{req}$ is greater than the available power $P_{avail}$, then $P_{avail}$ is added uniformly to generators at $Bus_n$ and removed uniformly from generators at $Bus_m$. The new dispatch values of the selected generators are also saved. This re-dispatch based on $P_{avail}$ would reduce the flow on

$Line_{kj}$ by $P_{red,kj}$. The value of this reduction is calculated using (6).

$$P_{red,kj} = \left|PTDF_{kj}^{nm} * P_{avail}\right| \quad (6)$$

The overload value is then updated using (7), where $P_{over,kj(t-1)}$ is the previous overload value.

$$P_{over,kj} = P_{over,kj(t-1)} - P_{red,kj} \quad (7)$$

If the update value of $P_{over,kj} \leq 0$ then the generator dispatch values are saved for implementation in ACPF, otherwise the algorithm continues, selecting a new set of generator buses for redispatch until $P_{over,kj} \leq 0$. Essential linear distribution factors are used to select the generators to redispatch and to calculate the required power adjustments.

## 3. Results on ERCOT 6102 Case Study

### *A. Case Study Description*

The ERCOT 6102-bus system, representing the Texas power grid, is used as the case study and modeled in PSS/E. However, the bus numbers and IDs have been scrambled to protect critical energy information. The original dataset contains 8761 hourly power flow cases representing the Texas power grid at different generation and loading conditions and was developed using data from U.S Energy Information Administration (EIA) as described in [8]. From the 8761 hourly power flow cases, 73 power flow cases failed to converge despite the application of various convergence techniques, including deep learning-based power flow initialization and homotopy continuation methods. The proposed generator re-dispatch algorithm is applied to these 73 non-converging ACPF cases in an attempt to solve it.

### *B. Result Analysis on Peak Load ACPF Dispatch*

The 73 non-converging ACPF cases include the peak load scenario, which has a total load of 79.8 GW. As described in the re-dispatch methodology, full Newton-Raphson power flow is first applied to the case and the active power bus mismatch of the diverged case is analyzed. From the diverged power flow case, the bus with the largest mismatch is identified as the critical bus ($Bus_{6000}$) as shown in Fig.2.

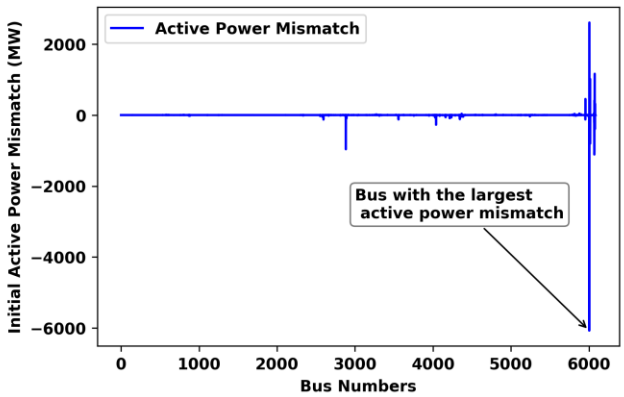


Fig. 2. Initial Active Power Bus Mismatch from Diverged ACPF Solution

The power flow model is then solved in DCPF to obtain a solution. Although this solution is not viable in ACPF it is used to identify the critical transmission line connected to $Bus_{6000}$ which is identified as $Line_{6000-6001}$. The critical transmission line has 5900.59 MW flowing through a line rated for 204.82 MW, resulting in a 5695.77 MW overload. The generator redispatch algorithm is then applied reducing the flow on the line to 97.3MW which causes the ACPF case to converge. The difference between the initial specified generator dispatch and the final converged dispatch is shown in Fig 3. The algorithm redispatches about 5.56 GW of power among 132 generators using linear distribution factors.

The reduction in line flow due to the re-dispatch can be observed in Fig.4. A significant difference in line flow exists between the initial DCPF solution of the diverged power flow model and the final converged ACPF solution. Negative flow simply means the flow is in the opposite direction. Additionally, the percentage of line loading decreased significantly as a result of the generator redispatch, as shown in Fig. 5.

Fig 6. shows the mismatch difference between the initial diverged ACPF case and the final converged ACPF case. The final converged ACPF case had a mismatch close to zero for all buses. Although the re-dispatch algorithm facilitated the convergence of the peak load case, it is important to investigate the quality of the converge ACPF case in terms of voltage magnitude.

The voltage magnitude of the final converged ACPF case is shown in Fig. 7, with about 4 buses violating the high (1.1pu) and low (0.9pu) voltage limits. To address the violations, switched shunts are added to the violating buses to supply or absorb reactive the required MVARs needed to maintain the voltage magnitude. The automated voltage violation solver described in [11] is used to add the switched shunts. This solver uses a QV analysis method to determine the size of the MVARs to be added. Although it does not guarantee the resolution of all voltage violations, it successfully reduces the number of violating buses in the peak load case from 4 to just 1, as shown in Fig. 8.

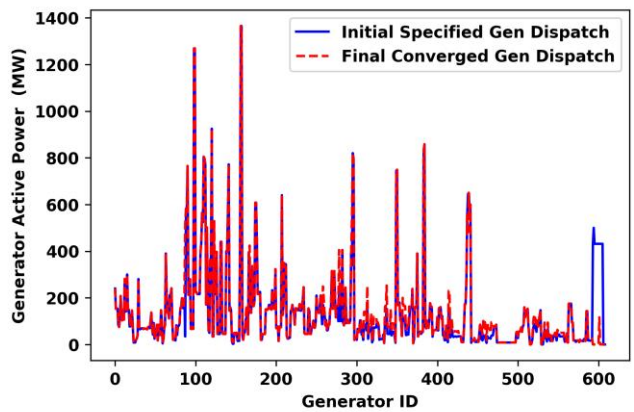


Fig. 3. Comparison between the initial specified generator dispatch and the final converged dispatch

*C. Result Analysis on the 73 Non-Converging ACPF Cases*

The generator redispatch algorithm was applied to the 73 non-converging ACPF cases, of which 64 successfully converged (including the peak load case) while 9 remained unsolved, as shown in Table I. Among the 64 converged ACPF cases, a typical case has about 3 buses with voltage violations. These violations were solved by adding switched shunts. The generator re-dispatch algorithm successfully converged 87.67% of the initial 73 non-converging cases. For comparison, the researchers in [12] converge 100% of their test power flow cases although only two power flow cases were used.

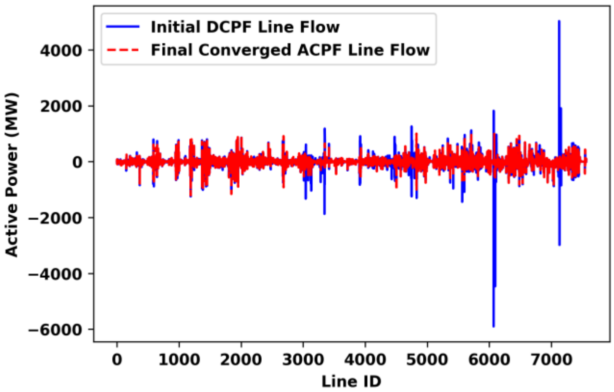


Fig. 4. Active Power Line Flow Comparison Between Initial DCPF Solution and the Final Converged ACPF Case

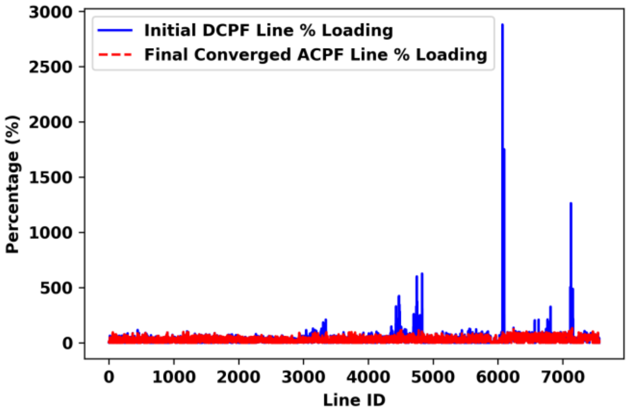


Fig. 5. Comparison on Percentage Line Loading

Table I Solved ACPF Cases via Generator Re-Dispatch

| Parameters | ACPF Cases |
|---|---|
| Initial Non-Converging Cases | 73 Cases |
| Solved Cases via Generator Re-Dispatch | 64 Cases |
| Remaining Unsolved | 9 Cases |

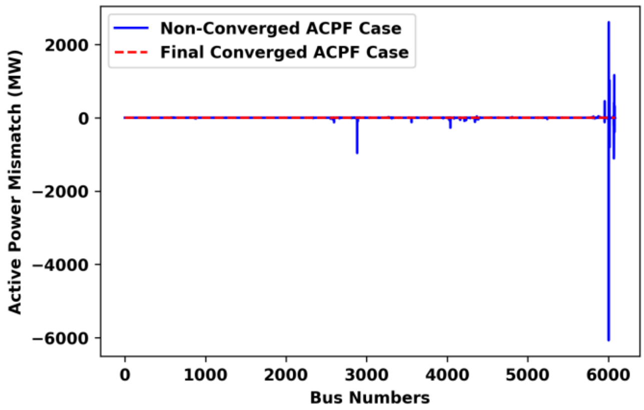


Fig. 6. Comparison on Bus Active Power Mismatch

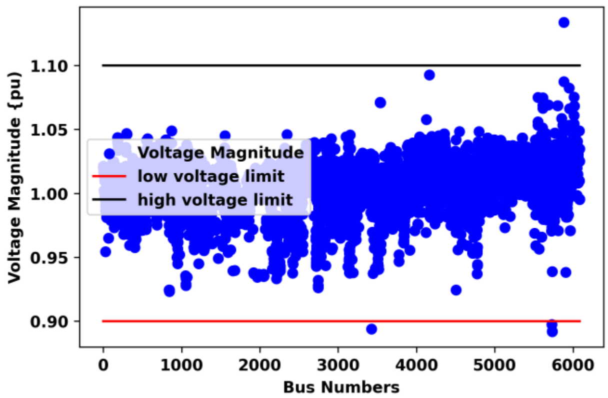


Fig.7 Voltage Magnitude of the Converged ACPF Case without extra reactive power support

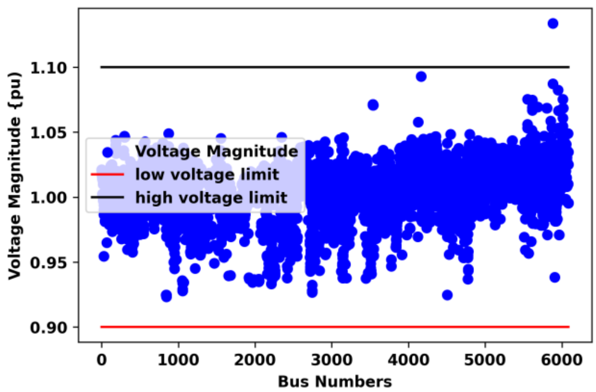


Fig.8 Voltage Magnitude of the Converged ACPF Case with extra reactive power support from switched shunts

## 4. Discussion and Conclusion

In this paper, a generator re-dispatch algorithm was successfully used to achieve convergence in 64 previously non-converging ACPF cases. The algorithm was able to identify overloaded transmission lines preventing the ACPF cases from converging and then redispatch the existing generators to alleviate the overload thus causing the power flow case to converge. The algorithm ensures that the re-dispatched powers are within the generator limits. It is important to note that the algorithm does not attempt to resolve all overloads rather it focuses on addressing only the critical overloads necessary to allow the case to converge. The algorithm was tested on the ERCOT 6102-bus under multiple operating conditions.

One limitation of the proposed re-dispatch algorithm is that it cannot resolve non-converging ACPF cases if the cause of the non-convergence is not related to congested critical transmission lines. This is evident in the remaining 9 non-converging ACPF cases. In such scenarios, other ACPF convergence methods must be explored, such as investigating potential local reactive power issues within the ACPF model.

The generator re-dispatch algorithm described in this paper is particularly valuable for grid planners, as it reduces the time and effort required to generate solved, converged power flow models. This is especially useful in power flow base case modeling and development in industry.

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