Resilience Development Approach for Smart Power Distribution System Coupled with Smart Green Transportation System on Cloud Computing Platform

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In a smart city, road traffic plays a crucial role in reducing traffic blockage, where the distributed generators (DGs) can energize, when power shortages occur in metropolitan areas. Present days,Urban transportation is a complex system with non-linear feedback loops and different variables affected by environmental factors, social factors, and transportation. In this paper, the resilience development approach by DG placement and line hardening for smart power distribution system coupled with the smart green transportation (SPDS-SGT) in the smart city infrastructure has been proposed. To minimize the cost of aggregating vehicle travel time and load shedding during DG placement tri-level optimization framework has been utilized [7]. Here The first stage is to obtain the DG placement and line hardening approach, Further the second stage is to find the fault line to increase the aggregating vehicle travel time and load shedding, and the final stage is to reduce the cost of travel and cost of load shedding. In the Smart Green transportation, the dynamic equilibrium of the user (DEU) is ascertained in a model for cell transmission (MCT) and resolved by a complementary linear method.The coupled SPDS-SGT is examined as two decoupled framework on cloud computing platform. Here, the equivalent bi-level model transformed from the tri-level method via Karush -Kuhn-Tucker (KKT) has been resolved using greedy search approach. The experimental results show that the effectiveness of the proposed system using case studies with a relevant method for coupled SPDS-SGT has shown prominent outcomes.

Keywords: Urban Transportation system, resilience, Power distribution system, traffic lights, traffic congestion.

1. Introduction

Strengthening the power system resilience in extreme weather events such as human operator missteps, malicious attacks, tornadoes, and hurricanes have turned a primary problem for the control of the power grid and its operations [1]. The power distribution system is a vulnerable part of the electrical structure and it suffers high power outages in developing countries. The power distribution system outages may lead to major electricity insufficiencies for performing traffic lights which play a significant role in the SmartGreen Transportation system (SGT) in a smart city infrastructure. SGT traffic lights with a suspendable power supply present the interaction of SGT and SPDS [2].

Transportation is an important part of the urban area in developing smart cities. Several advantageous forms of smart green transportation support and improve walkable urbanism [3] has been analysed in the recent research [4]. The smart green transportation options make individual lives easier, which helps to reduce our dependence, reduce congestion on cars and oil, Further, it is safer and less costly, to save the planet [21]. Nowadays, The greenest and most supportable forms of transportation are bicycles, trains, and walking. The single most powerful transportation choice that can solve serious economic, mobility, energy, health, environmental, and social problems on a global scale [5] has been depicted in the figure 1 that explains about the smart green transportation in a smart city.

To improve the resilience of power distribution system for extreme weather conditions, Line hardening is one of the techniques which is used for cost-effective analysis. The line hardened cannot survive any outages as discussed in the research paper [6]. There are different hardening approaches, utilizing reinforcing overhead lines, underground cables, enhancing power poles, enhancing vegetation management, relocating vulnerable facilities, and upgrading substations [22]. The hardening of the entire distribution system is more expensive and to constraint the line hardening cost, power distribution system resilience has been proposed using a two-level optimization paradigm for line hardening method which reduces the detriment over natural hazards sustained in a DS. Few Researchers suggested fragility infrastructure models for the enforcement of strategies of resilience involving the line hardening in SPDS [8].

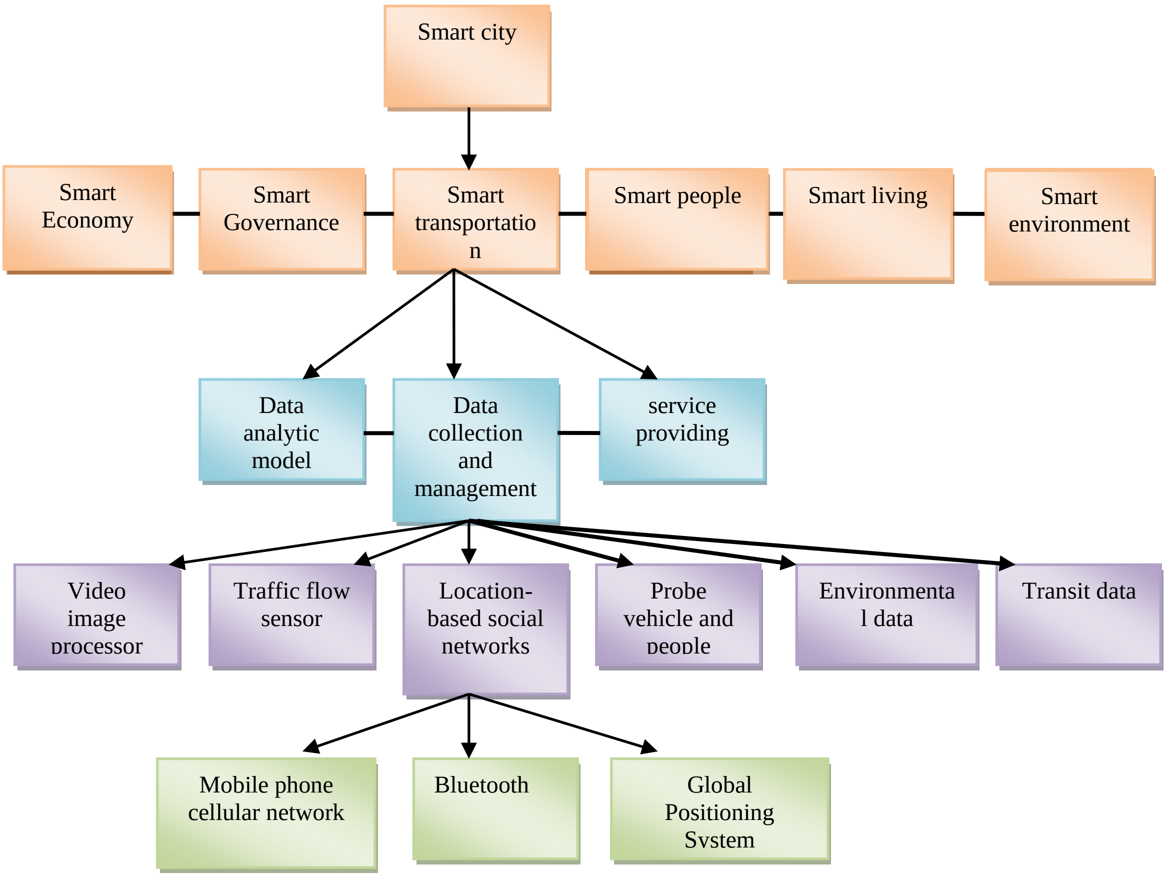

Fig 1: Smart green transportation in smart city architecture

For a smart city, economic line hardening strategies include pole replacement, refurbishment, and durability resilence has been analyzed. The integration of DG gives an another method to develop a SPDS for more versatile and robust nature. Under general operating terms [9], a robust two-level optimization paradigm is proposed for the positioning and sizing of DG units to enhance the SPDS flexibility to Boost PDS resilience towards volatility in renewable resources [12]. Besides, facing power shortages in extreme weather events, SPDS can recover vital loads by forming DG-energized networked microgrids. In extreme weather conditions, optimum DG placement and line hardening methods has been analyzed which provide a feasible model for resilience enhancement system [10]-[11].

We also acknowledge that SGT traffic lights could be impacted by extreme weather event outages in the smart city infrastructure [23]. Traffic lights play an important role in strategic traffic handling which impacts SGT time of vehicle travel. Traffic light outages minimize SGT traffic power and deteriorate rapidly peak-hour congestion and the efficiency of traffic flow in urban settings. The coupled SPDS-SGT handled by local microgrids capable of providing power services for vital loads for enhancing the SGT performance, traffic lights [13].

Charging of electric vehicle scheduling is typically considered in a SPDS- SGT paradigm as the concentrate area that connects the two physical systems. Certain research centered on the short-term specifications of wireless charging stations which has highlights on the connection with SPDS and SGT [14]. The number of SGT electric vehicles, which maintain the flow of traffic, determines the SPDS power demand battery swapping stations and on-road charging [15]. Tan et al [16] introduce the integrated electric vehicle charging navigation system for a coupled PDS-UTS. Nevertheless, the analysis fails to find traffic light shortages led by PDS errors that directly affect the UTS traffic flow of electric vehicles. There is also a relatively low percentage of UTS electric vehicles and a static model of the user equilibrium as the solution to the problem of traffic assignment is not working when traffic lights are an outage.

In this paper, the resilience development strategy in extreme weather events for the power distribution network coupled with the smart green transportation in the smart city has been proposed. Considering the previous studies, we connect the SGT with SPDS and traffic light outages. Chiu et al [17] proposed the static model of the user equilibrium for UTS to demonstrate the time of steady-state travel but the traffic light of modeling transportation was not considered. Here We have been proposed the dynamic equilibrium of the user (DEU) model in SGT that provides various choices for route and departure time. In particular, the model of the cell transmission (MCT) has been proposed to resolve the DEU issue with varied over time PDS and SGT demand interdependency in traffic connection. Han et al [24] presented as a linear complementarity mathematical model for the DUE issue with an embedded MCT.

A tri-stage optimization-based robust decision assist method of the better results has the coordinates of DG placement and line hardening strategies that improves the coupled PDS-SGT resilience in extreme weather events [19]-[20]. The major endowment of this paper is outlined as following statements:

(I) Combine the MCT-based SGT paradigm for determining the resilience development approach in a coupled PDS-SGT that would despise the interaction of the two physical frameworks. Further, the distribution of traffic flow is explained by DEU via reviewing the influence of traffic light shortages [18].

(II) Establish the MCT-based SGT paradigm as a linear complementarity challenge embedded in the third stage of the stable resilience development model in the tri-stage. Using Karush-Kuhn-Tucker (KKT) terms to convert the tri-stage optimization process into an equivalent bi-level MILP. Initiate an efficient greedy search method to solve the identical bi-level MILP.

(III) Further, The proposed SPDS-SGT tri-stage optimization system can be further increased to the site and scale of new DGs and battery swapping method, on-road charging stations for electric vehicles.

The correlation art of this research paper is arranged as follows. Where the Section 2 discussed the condition formulation and MCT-based SGT model of complementarity method with the SGT in an outage of traffic lights. The proposed numerical formulation of the tri-stage optimization model algorithm and the greedy search approach has been discussed in section 3. Numerical case studies are provided in Section 4. In Section 5 conclusion has been discussed.

B. Development of Modelling Transportation for smart city infrastructure

In this paper, the development of resilience strategy in extreme weather events for the power distribution network coupled with the smart green transportation in the smart city has been proposed.In this part, the complementarity issues, preparation of the DEU model for utilizing the MCT in the SGT network with various route choices and departure time is validated. Besides, In origin-destination (O-D) pair incorporates traffic signal intersections, where several miserly drivers will pay the travel and compensate for arriving at the destination early or late. DEU indicates that total lowest cost travel to a provided O-D pair for every traveler and The estimation of travel time model in the MCT which depends on the SGT model as discussed as follows.

(i) Model for Cell Transmission

In Lighthill-Whitham-Richards model as mentioned as the conventional MCT is a hydrodynamic discrete interpretation traffic flow theory, Where the Cells in this model hold physical size, and connections that assist the objective of communication, unlike a link-node representation. In MCT, it is important to satisfy the request of every O-D pair:

$$\sum_{q\in Q^{\omega}}\sum_{d=0}^{D_t} e_{q,d} = t^{\omega}, \forall\omega \in W \quad (1)$$

As shown in the equation (1) where W is the set of O-D Paris, where q is the index for paths, ω indicates Indices for pairs of origin-destination (O-D), Q is the set of every paths, D_t set of departure time.

The occupancy of cell equation flow and update computation are provided as follows.

occupancy of cell update:

Proposition 1:

$$y_{q,0}^{j} = 0, \forall j \in B; q \in Q \quad (2)$$

$$x_{q,0}^{j,i} = 0\ \forall j \in B; q \in Q \quad (3)$$

As shown in the equation (2) and (3) given the traffic conditions d=0 initialization.

$$y_{q,d}^{j} = y_{q,d-1}^{j} + e_{q,d-1} - x_{q,d-1}^{j,i}, \forall j \in B_o; j,i \in q; i \in \Gamma_j; d = 1, K, D_t + 1 \quad (4)$$

$$y_{q,d}^{j} = y_{q,d-1}^{j} - x_{q,d-1}^{l,j}, \forall j \in B_o; j,i \in q; i \in \Gamma_j; d = D_t + 2, K, D_m \quad (5)$$

$$y_{q,0}^{j} = 0, \forall j \in B_o; j \notin q; d = D \quad (6)$$

The mathematical formulation (4),(5) and (6), $e_{q,d-1}$ Denotes the demand pattern and getting information of traffic directly and the orgin cells stores large sum of traffic data.

$$y_{q,d}^{j} = y_{q,d-1}^{j} - x_{q,d-1}^{j,i}, \forall j \in B_E V B_I; j,i,l \in q; l \in \Gamma_j^{-1}; i \in \Gamma_i; d \in D \quad (7)$$

$$y_{q,d}^{j} = 0, \forall j \in B_E V B_I; j \notin q; d = D \quad (8)$$

From the mathematical computation of (7) and (8) in MCT, every intersection and ordinary cell in path q holds one downstream and one upstream link.

$$y_{q,d}^{j} = y_{q,d-1}^{j} + x_{q,d-1}^{l,j}, \forall j \in B_R; j,l \in q; l \in \Gamma_j^{-1}; d \in D \quad (9)$$

The Representation of the destination cells, limitation as decreased as formulated in the equation (9).

(ii) Flow Calculation of the conventional MCT:

Proposition 2:

Let's consider that $M_j = \infty$ and $P_j = \infty$. In the conventional MCT, the traffic flow from the cell j to cell i, is unable to complete due to interdependency, as estimated at the disaggregated level and aggregate level, Further the following equation (10) and (11) are expressed as follows,

$$x_d^{-j,i} = \min\left\{y_d^{-j}, P^j, P^i, \rho\left(M^i - y_d^{-i}\right)\right\}, \forall j \in B - B_I, i \in \Gamma_j, d = D \quad (10)$$

$$x_{q,d}^{j,i} = x_d^{-j,i} \times [y_{q,d}^{j} / (y_d^{-j} + \sigma)], \forall j \in B - B_I, i \in \Gamma_j, q \in Q, d = D \quad (11)$$

As shown in the equation (11) where $\boldsymbol{y_{q,d}^{j}}$ denotes that proportion of path-based occupancy of cells and $\boldsymbol{y_d^{-i}}$ denotes the aggregate occupancy of cells as utilized to obtain the path flow $\boldsymbol{x_{q,d}^{j,i}}$ and $\boldsymbol{\sigma}$ indicate an infinitesimal number.

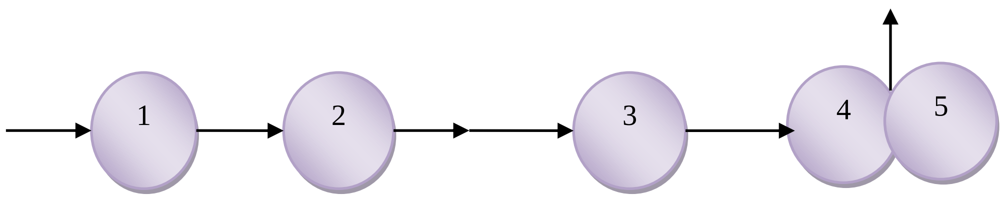

Fig 2: Various cell types utilized in model preparation

A binary variable $\boldsymbol{\omega_d^{(j,j')}}$ is presents for the control of traffic light that enables the intersection cell {1,2,3,4,5} to act as a normal cell through only one successor and one predecessor. The flow limitation equation (10) and equation (11) for the cell intersection j are altered as:

$$\boldsymbol{x_d^{-j,i} = min\left\{y_d^{-j}, P^j, \omega_d^{(j,j')} P^i, \rho\left(M^i - y_d^{-i}\right)\right\}, \forall (j,j') \in B_I, i \in \Gamma_j, d = D}$$

$$\boldsymbol{x_{q,d}^{j,i} = x_d^{-j,i} \times [y_{q,d}^{j} / (y_d^{-j} + \sigma)], \forall (j,j') \in B_I, i \in \Gamma_j, q \in Q, d = D} \quad (12)$$

Then $\boldsymbol{\omega_d^{(j,j')}}$ satisfies,

$$\boldsymbol{\sum_{\tau=d}^{d+D_{min,j}^F} \left|\omega_d^{(j,j')} - \omega_{d-1}^{(j,j')}\right| \leq 1, d \in D} \quad (13)$$

$$\boldsymbol{\sum_{\tau=d}^{d+D_{min,j}^F} \omega_d^{(j,j')} \leq D_{min,j}^F, \forall (j,j') \in B_I; d = 0, 1, K, D_m - D_{min,j}^F} \quad (14)$$

$$\sum_{\tau=d}^{d+D_{min,j}^{F}}\left(1-\omega_{d}^{(j,j')}\right) \leq D_{min,j}^{F}, \forall (j,j') \in B_I; d=0,1,K,D_m-D_{min,j}^{F} \quad (15)$$

As shown in the equation (13)-(15) the SGT timing of a traffic signal is adjusted respectively to flow of traffic , and the binary decision variable of traffic light is $\omega_{d}^{(j,j')}$. If outages of traffic lights, stop signs ought to be utilized in which red and green light time are simulated to be the same, which satisfies,

$$D_{max,j}^{F} = D_{min,j}^{F} = D_{wait} \quad (16)$$

As shown in the equation (16) where D_{wait} is a wait time of the pre-set at the interaction j. where the binary variable $\xi^{(j,j')}$ initialized for pretending the two stages of traffic light $D_{max,j}^{F}$ and $D_{min,j}^{F}$ substitute in equation (13) - (15), the following equation (17) is expressed as follows,

$$D_{max,j}^{F} = \xi^{(j,j')} D_{max,j}^{F} + \left(1-\xi^{(j,j')}\right) D_{wait}, \forall (j,j') \in B_I \quad (17)$$

$$D_{min,j}^{F} = \xi^{(j,j')} D_{min,j}^{F} + \left(1-\xi^{(j,j')}\right) D_{wait}, \forall (j,j') \in B_I$$

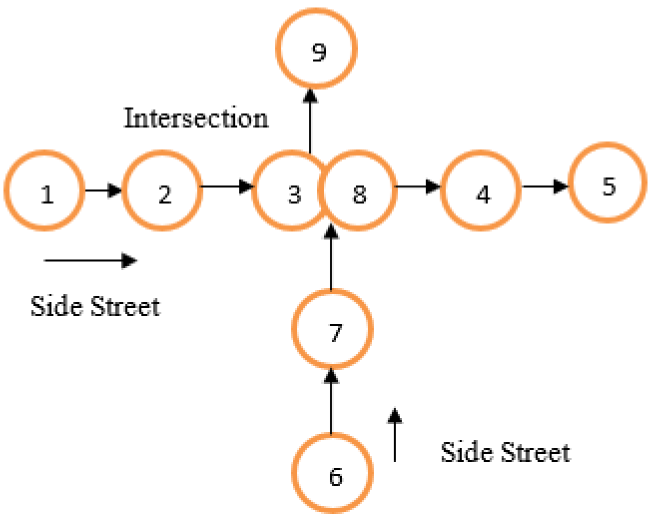

Fig 3: MCT example

Considering the intersection of cells fig 3 provides the example of one-way arterial where j=1-5. The arterial is separated into 5 cells and the side street is separated in 4 cells. Occupancy of cells and flow computation are performed on the basis of type cells. Every O-D pair has its traffic demand t^{ω}.The origin cells are 1 and 6 and the destination cells 5 and 9 has the O-D cell pair (3,8) which denotes traffic lights intersection. The remaining cells are ordinary.

(iii) Estimation model of travel time

Proposition 3:

The model for maximum travel time has been used for departures in every time interval with every path. MMTT is transformed into a set of complementarity linear conditions to solve the estimation. The cumulative arrivals and departure patterns are used to estimate the travel time.

$$\boldsymbol{\mathcal{M}_{q,d,d'}} = \begin{cases} \mathbf{1} & \boldsymbol{if}\ \sum_{\tau=0}^{d} \boldsymbol{e_{q,\tau}} - \boldsymbol{y_{q,d'}^{t}} > \mathbf{0}\ \forall \boldsymbol{q} \in \boldsymbol{Q}; \boldsymbol{t} \in \boldsymbol{q}; \boldsymbol{t} \in \boldsymbol{B_G} \\ \mathbf{0} & \boldsymbol{if} \sum_{\tau=0}^{d} \boldsymbol{e_{q,\tau}} - \boldsymbol{y_{q,d'}^{t}} < \mathbf{0}, \boldsymbol{d} \in \boldsymbol{D_G} \\ [\mathbf{0},\mathbf{1}]\ \boldsymbol{if}\ \sum_{\tau=0}^{d} \boldsymbol{e_{q,\tau}} - \boldsymbol{y_{q,d'}^{t}} = \mathbf{0}\ \boldsymbol{d'} = \boldsymbol{d}, \boldsymbol{d}+\mathbf{1}, \boldsymbol{K}, \boldsymbol{D_m} \end{cases} \tag{18}$$

As shown in the equation (18) where the departure aggregate on q path up to time $\sum_{\tau=0}^{d} \boldsymbol{e_{q,\tau}}$ is according to destination cell occupancy factor t on this path. $\boldsymbol{\mathcal{M}_{q,d,d'}}$denotes the departure on path q up to time $\boldsymbol{d} \in \boldsymbol{D_t}$ arrived at destination.

Correspondingly the path q travel time for time period d vehicles departing is provided as the following equation (19) is,

$$\boldsymbol{DD_{q,t}} = \sum_{d'=d}^{D_m} \boldsymbol{\mathcal{M}_{q,d,d'}} = \sum_{d'=d}^{D_m} (\mathbf{1} - \widehat{\boldsymbol{\mathcal{M}}}_{q,d,d'}) \tag{19}$$

Equation (18) is replaced with complementarity linear form the following equation (20) expressed as,

$$\begin{cases} \mathbf{0} \le \boldsymbol{\theta_{q,d,d'}} \perp \mathbf{1} - \widehat{\boldsymbol{\mathcal{M}}}_{q,d,d'} \ge \mathbf{0} \quad \forall \boldsymbol{q} \in \boldsymbol{Q}; \\ \mathbf{0} \le \widehat{\boldsymbol{\mathcal{M}}}_{q,d,d'} \perp \sum_{\tau=0}^{d} \boldsymbol{e_{q,\tau}} - \boldsymbol{y_{q,d}^{t}} + \boldsymbol{\theta_{q,d,d'}} \ge \mathbf{0}, \boldsymbol{d} = \mathbf{0}, \boldsymbol{K}, \boldsymbol{D_t}; \\ \boldsymbol{\mathcal{M}_{q,d,d'}} = \mathbf{1} - \widehat{\boldsymbol{\mathcal{M}}}_{q,d,d'} \boldsymbol{d'} = \boldsymbol{d}, \boldsymbol{K}, \boldsymbol{D_m} \end{cases} \tag{20}$$

(iii) Dynamic equilibrium model

For every O-D pair$\boldsymbol{\omega}$ and a path connecting $\boldsymbol{\omega}$ such as $\boldsymbol{q} \in \boldsymbol{Q^{\omega}}$at every time period d of dynamic equilibrium condition has been utilized. if the rate of departure $\boldsymbol{e_{q,d}}$ is absolute then the total cost are equivalent and minimum. Complementarity condition is converted form this condition as following the equation (21) is expressed by,

$$\mathbf{0} \le \boldsymbol{e_{q,d}} \perp \boldsymbol{\delta^{\omega} DD_{q,d}} + \boldsymbol{\gamma^{\omega} DE_{q,d}} + \boldsymbol{\alpha^{\omega} DS_{q,d}} - \boldsymbol{B_{\omega}^{*}} \ge \mathbf{0}, \forall \boldsymbol{\omega} \in \boldsymbol{W}, \boldsymbol{q} \in \boldsymbol{Q^{\omega}}, \boldsymbol{d} \in \boldsymbol{D} \tag{21}$$

As shown in the equation (21) where $\boldsymbol{DE_{q,d}}$, $\boldsymbol{DS_{q,d}}$ and $\boldsymbol{DD_{q,d}}$,are early arrival time, late arrival and travel time correspondingly. $\boldsymbol{B_{\omega}^{*}}$denotes the O-D pair $\boldsymbol{\omega}$ of minimum travel time.

The early arrival time is expressed by,

$$\boldsymbol{DE_{q,d}} = \boldsymbol{max}\left(\mathbf{0}, \boldsymbol{d_{\omega}^{*}} - \boldsymbol{d} - \boldsymbol{DD_{q,d}}\right), \forall \boldsymbol{q} \in \boldsymbol{Q^{\omega}}, \boldsymbol{d} \in \boldsymbol{D} \tag{22}$$

The late arrival time is expressed by,

$$\boldsymbol{DS_{q,d}} = \boldsymbol{max}\left(\mathbf{0}, \boldsymbol{d} + \boldsymbol{DD_{q,d}} - \boldsymbol{d_{\omega}^{*}}\right), \forall \boldsymbol{q} \in \boldsymbol{Q^{\omega}}, \boldsymbol{d} \in \boldsymbol{D} \tag{23}$$

$$\mathbf{0} \le \boldsymbol{DE_{q,d}} \perp \boldsymbol{DE_{q,d}} - (\boldsymbol{d_{\omega}^{*}} - \boldsymbol{d} - \boldsymbol{DD_{q,d}}) \ge \mathbf{0}, \forall \boldsymbol{q} \in \boldsymbol{Q^{\omega}}, \boldsymbol{d} \in \boldsymbol{D} \tag{24}$$

$$\boldsymbol{DS_{q,d}} = \boldsymbol{DE_{q,d}} - (\boldsymbol{d_{\omega}^{*}} - \boldsymbol{d} - \boldsymbol{DD_{q,d}}) \ge \mathbf{0}, \forall \boldsymbol{q} \in \boldsymbol{Q^{\omega}}, \boldsymbol{d} \in \boldsymbol{D} \tag{25}$$

As shown in the equation (24) and (25) where $\boldsymbol{d_{\omega}^{*}}$ indicates the O-D pair $\boldsymbol{\omega}$ of preferred arrival time.

The common complementary condition $\mathbf{0} \leq \boldsymbol{b} \perp \boldsymbol{w} \geq \mathbf{0}$ substitutes by an equal set of limit the following equation (21) is expressed by,

$$\begin{cases} \boldsymbol{S} \cdot \boldsymbol{\beta} \leq \boldsymbol{b} \leq \boldsymbol{V} \cdot (\mathbf{1} - \boldsymbol{\beta}) \\ \boldsymbol{S} \cdot \boldsymbol{\beta} \leq \boldsymbol{w} \leq \boldsymbol{V} \cdot \boldsymbol{\beta} \\ \boldsymbol{b} \geq \mathbf{0}, \boldsymbol{w} \geq \mathbf{0}, \boldsymbol{\beta} \in \{\mathbf{0}, \mathbf{1}\} \end{cases} \tag{26}$$

As shown in equation V and S denotes that very large positive constants and negative correspondingly.

2. Tri-stage optimization model for problem formulation

A tri-stage optimization model has been proposed and shown in figure 4 to reduce the cost of load shedding in extreme weather events through constraint resources for DG placement and line hardening. The first stage reduces the resilience measures such as travel cost of SGT and cost of SPDS load shedding impact by extreme weather events which obtains lines that must be nodes and hardened includes DGs. The next stage is designed to maximize the damages to SGT and SPDS such as the load shedding cost in SPDS and SGT travel cost is analyzed. The SGT and SPDS are decoupled once the hard extreme weather event scenario is obtained at this stage. The final stage separated into two sections to reduce the SGT travel cost and cost of SPDS load shedding correspondingly is depicted in the Figure 4 that explains the proposed tri-stage optimization model briefly.

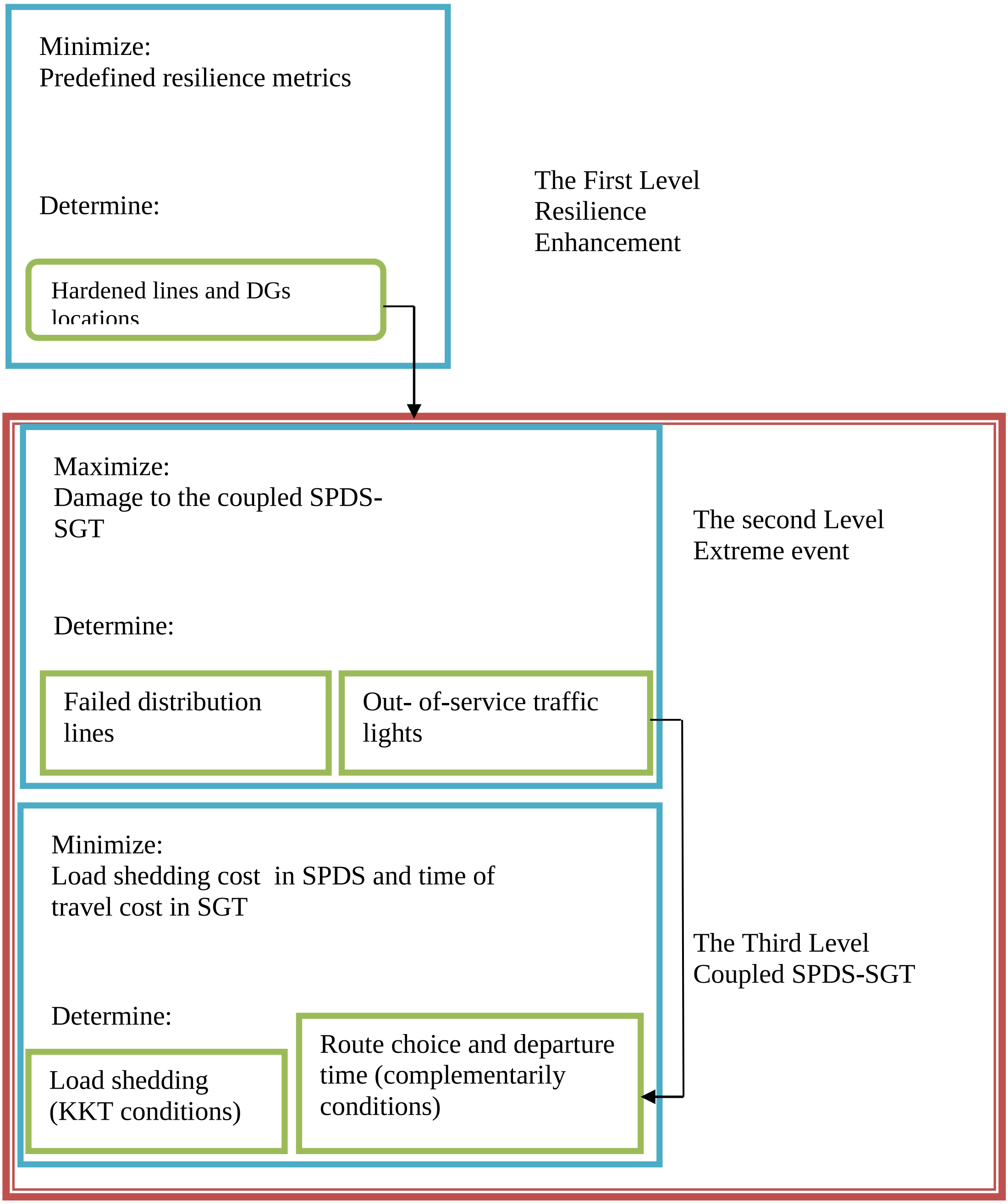

Fig 4: resilience development tri-stage optimization model

Algorithm 1: The proposed tri-stage optimization algorithm

Input: j, i, m

Output: $\boldsymbol{G_1(k,v)}$, $\boldsymbol{G_2(k,v)}$

For k=0$\min_{k \in K} \max_{v \in V} \min_{(o,x) \in G(k,v)} [B_{PDS}(o) + B_{UTS}(x)]$

For j=0$B_G(k) = \sum_{(j,i) \in \Omega_S} b_{ji}^k . k_{ji} + \sum_{m \in \Omega_M} b_m^\beta . \beta_m \leq C_{KF}$

$$B_{PDS}(o) = \sum_{m \in \Omega_M} b_m^{ha} . Q_m^{ha}$$

$$B_{UTS}(x) = \sum_{\omega \in W, q \in Q^W} \sum_{d \in D} \delta^\omega DD_{q,d} + \gamma^\omega DE_{q,d} + \alpha^\omega DS_{q,d}$$

For i=0$K = \{ K | \sum_{(j,i) \in \Omega_S} k_{ji} \leq C_K, \sum_{m \in \Omega_M} \beta_m \leq C_F \}$

If $C_T = 0 \quad V = \{ v | \sum_{(j,i) \in \Omega_S} (1 - v_{ji}) \leq C_T \}$

else $G(k,v) = G_1(k,v) \times G_2(k,v)$

For m=0 $G_1(k,v) = \{ 0 | \sum_{j|(m,j) \in \Omega_S} Q_{mj} = \sum_{i|(i,m) \in \Omega_S} Q_{im} + F_m^q + Q_m^{ha} - Q_m, \forall m \in \Omega_M \, [\Psi_m^1]$

For h=0 $\sum_{j|(m,j) \in \Omega_S} P_{mj} = \sum_{i|(i,m) \in \Omega_S} P_{im} + F_m^q + P_m^{ha} - P_m / Q_m, \forall m \in \Omega_M [\Psi_m^2]$

$$U_i = U_j - \frac{T_{ji} Q_{ji} + Y_{ji} P_{ji}}{U_0}, (j,i) \in \Omega_S [\Psi_{ji}^3]$$

End for

End for

End for

If$0 \leq F_m^q \leq \beta_m \cdot F_m^{max}, m \in \Omega_S \qquad [\sigma_m^1, \sigma_m^2]$

else$0 \leq F_m^p \leq P_m, m \in \Omega_M \qquad [\sigma_m^3, \sigma_m^4]$

If$0 \leq Q_m^{ha} \leq P_m, m \in \Omega_M \qquad [\sigma_m^5, \sigma_m^6]$

Else$U_{min} \leq U_m \leq U_{max}, m \in \Omega_M \qquad [\sigma_m^7, \sigma_m^8]$

$$-Q_{ji}^{max} \leq Q_{ji} \leq Q_{ji}^{max}, (j,i) \in \Omega_S \qquad [\sigma_{ji}^9, \sigma_{ji}^{10}]$$

$$-P_{ji}^{max} \leq P_{ji} \leq P_{ji}^{max}, (j,i) \in \Omega_S \qquad [\sigma_{ji}^{11}, \sigma_{ji}^{12}]$$

$$-N_1 \cdot (k_{ji} + v_{ji}) \leq Q_{ji} \leq N_1 \cdot (k_{ji} + v_{ji}), (j,i) \in \Omega_S [\sigma_{ji}^{13}, \sigma_{ji}^{14}]$$

$$-N_2 \cdot (k_{ji} + v_{ji}) \leq P_{ji} \leq N_2 \cdot (k_{ji} + v_{ji}), (j,i) \in \Omega_S [\sigma_{ji}^{15}, \sigma_{ji}^{16}]$$

For $j' = 0 \xi^{(j,j')} \leq Q_m \cdot (Q_m - Q_m^{ha^*}), \forall (j,j') \in B_I; \forall m \in \Omega_M$

$$\xi^{(j,j')} \geq (Q_m - Q_m^{ha^*}) / Q_m, \forall (j,j') \in B_I; \forall m \in \Omega_M$$

$$G_2(k,v) = \{x|MTC: equation(1-17)\ \ MMTT: equation(19-20)\ \ DEU\ condition: equation(20-25)\}$$

End if

End for

End if

End for

Return

Nomenclature Details for the Algorithm.1 is tabulated as follows:

Table 1: Symbol Description

q	Indices for pathway
$\boldsymbol{\omega}$	Indicesfor origin-destination pairs
j,i	Cell index in urban transport system or power distribution system nodes.
D	time interval indexin UTS
(j,i)	directed line index from j to i in SPDS
W	O-D pairs
Q	Index of every path
B	Cells
$\boldsymbol{B_O}$	Origin cells
$\boldsymbol{B_E}$	Ordinary cells
$\boldsymbol{B_R}$	Destination cells
$\boldsymbol{B_I}$	Intersection cells
$\boldsymbol{\Gamma_j^{-1}},\ \boldsymbol{\Gamma_j}$	Predecessors/successors of cell j
$\boldsymbol{D_t}$	Departure time
D	Time intervals
$\boldsymbol{D^F_{max,j}}, \boldsymbol{D^F_{min,j}}$	At intersection cells, maximum and minimum green time of traffic signal
$\boldsymbol{\sigma}$	Shock wave propagation ratio
$\boldsymbol{y^j_{q,d}}$	Cell j occupancy at time d path flow $\boldsymbol{q} \ni \boldsymbol{j}$
$\boldsymbol{x^{j,i}_{q,d}}$	Cell flow j to i cell at time d on path q $\boldsymbol{j} \in \boldsymbol{q}, \boldsymbol{i} \in \boldsymbol{\Gamma_j}$
$\boldsymbol{G_1(k,v)}$	SPDS action constraints utilizing the Resilience development strategy k in extreme weather event v
$\boldsymbol{G_2(k,v)}$	SGT action constraints utilizing the Resilience development strategy k in extreme weather event v
G(k,v)	Collection of operational constraints for the combined SPDS-SGT in extreme weather events using the resilience development strategy k.
V	Set of extreme weather events uncertainty

$\boldsymbol{\Omega_M}$	SPDS nodes
$\boldsymbol{\Omega_S}$	SPDS lines

Algorithm 2: Greedy Search Approach

1. Initialization : set $\boldsymbol{\Gamma \leftarrow 0, u \leftarrow 0, D = 0}$;

2. While $\boldsymbol{B_E < B_I}$

3. Solve $\boldsymbol{D^F_{min,j}}$ and determine its optimal solution $\boldsymbol{D^F_{max,j}}$ and determine critical lines and nodes

4. Update $\boldsymbol{u \leftarrow u + 1}$, choose the critical node and line in $\boldsymbol{\Gamma_j}$ to be hardened, solve $\boldsymbol{D_{wait}}$and installed with DG,

5. Solve $\boldsymbol{D^F_{min,j}}$ and determine its optimal solution $\boldsymbol{DD_{q,t}}$ and update $\boldsymbol{\Gamma_j}$ by adding $\boldsymbol{\Gamma_j, \Gamma_j}^{-1}$

6. End while

7. Return

As inferred From the Algorithm.1. and Algorithm.2, To resolve the identical bi-level issue, a greedy search method has been proposed. The algorithm iteratively creates new vital nodes and lines in a set $\boldsymbol{\Gamma_j}$. In iteration$\boldsymbol{\Gamma_j}^{-1}$, the high vital node and line in are chosen to equip and hardened with DG in a constrained resources. The $\boldsymbol{D^F_{min,j}}$ attributes will be changed once anode and a line is selected in iteration$\boldsymbol{\Gamma_j}$. The solution of S(k) will select a particular critical node and line in Γ . The algorithm ends after the reversing resources is consumed. For a specified resilience development strategy, update the hard scenario to be involved in Γ.

3. Case studies

(i) Line Hardening Effectiveness

In order to verify the efficiency of line hardening in the combined SPDS and SGT, load shedding costs and UTS travel costs is addressed with different line hardening tools. The optimal resilience development strategy for DG placement and line hardening, respectively, to travel cost, load shedding cost and hard-case damaged lines are validated. Further line hardening will reduce the cost of load shedding, but it may not always be possible to reduce travel costs. This is because our model reduces the total cost as such in load shedding costs plus travel costs to enable the proper resilience development strategy due to the resilience enhancement options available in both SPDS and SGT as listed in the fig 5(a) and 5(b)that explains about various line hardening budgets and voltage profiles.

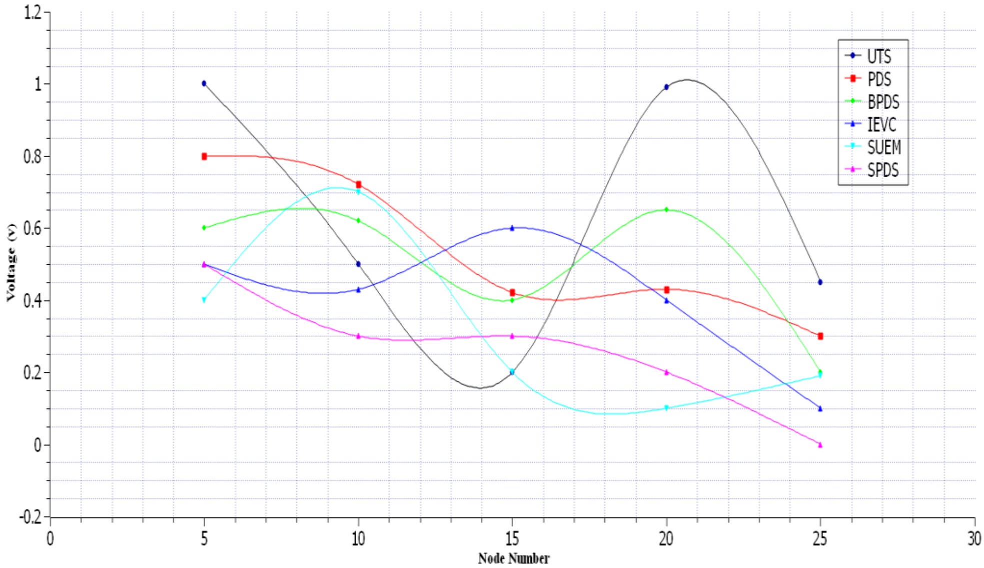

Fig 5(a): voltage profiles utilizing various line hardening budgets

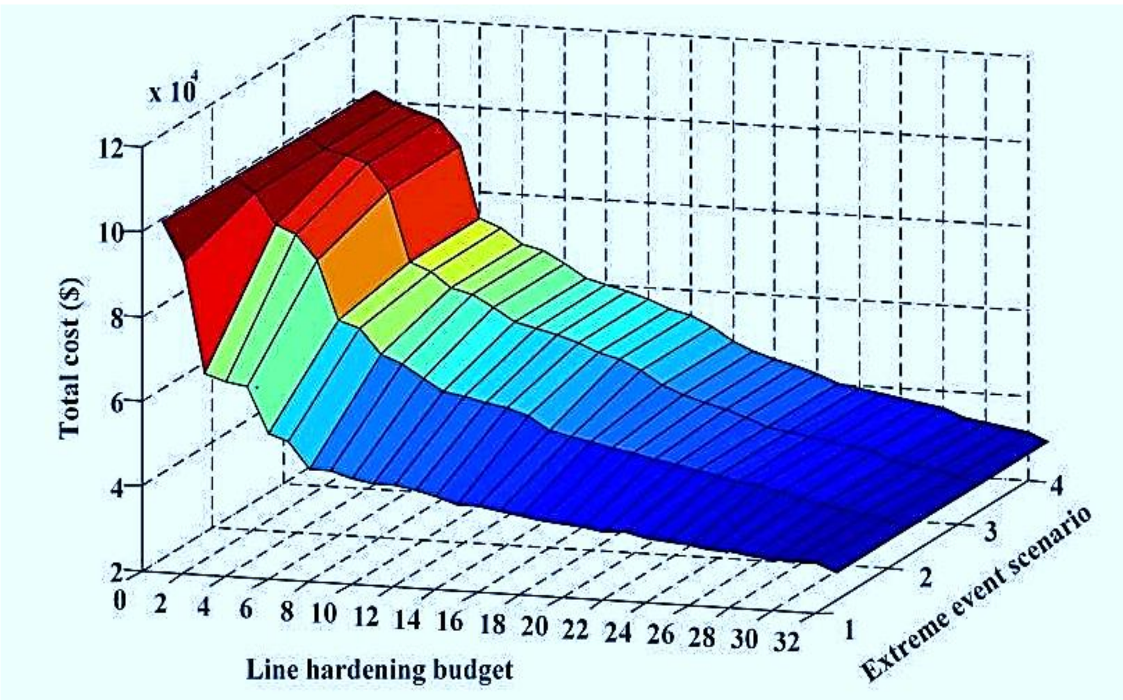

Fig 5(b): Total cost utilizing different line hardening resources and extreme weather events for coupled SPDS-SGT

(ii) DG placement Impacts

The DGs can provide power to respective loads of microgrid when SPDS has an out-of-service. To examine the significance of the DG placement ideal in SPDS in a specific extreme weather event scenario. Resilience improvement by maximizing the number of line hardening cases and DGs in the coupled S6PDS-SGT. Fig. 6 and table 2 shows the travel costs and load shedding for different DGplacement and line hardening budgets in a particular extreme weather event scenario as shown in the Fig.6..

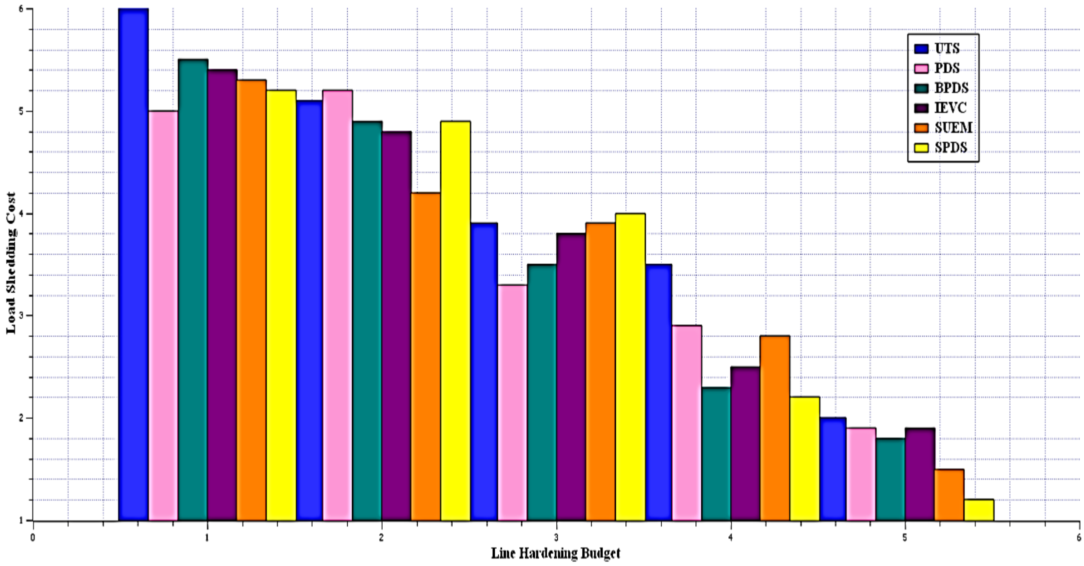

Fig 6: Influence of DG placement on resilence of coupled SPDS-SGT

The efficiency of system resilience improvement as regards decreases travel costs and load shedding in a specific extreme weather event scenario is considerably enhanced by DG placement. The measures of DG placement for improving the resilience of power system over natural hazards are explained.In this case, when an extreme weather event impacts an SPDS, loads could be picked up by DGs that containing SGT traffic lights disconnected from the main grid. Our case studies show that DG scan enhance the resilience of SGT and SPDS by making microgrids that would help the respective loads as shown in the Table.2. for numerical consistency.

Table 2: Line Hardening Budgetvs load shedding cost and travel cost

Line Hardening budget	UTS	PDS	BPDS	IEVC	SUEM	SPDS
1	6	5.9	5.8	5.6	5.7	5.6
2	5.1	4.9	4.9	4.3	4.2	4.1
3	3.9	3.8	3.4	4.5	3.9	3.2
4	2.9	2.8	3	3.2	3.1	2.8
5	2	1.9	1.7	1.3	1.5	1.2

(iii) Analysis of DG placement and Line Hardening

The outages of traffic light executed as a stop sign which decrease the traffic potential in the point of intersection while another accessible traffic lights can adapt the green light periodin accordance to flow of traffic. Accordingly, the cost of travel expands. The mainstream case studies indicate the stable benefit of the proposed SGTmodel to resolve the DEU issue taking into account inaccessible traffic lights and the fig 7 explains the Coupled SPDS-SGT costs for different system resilience development budget and extreme weather events under hurricane.

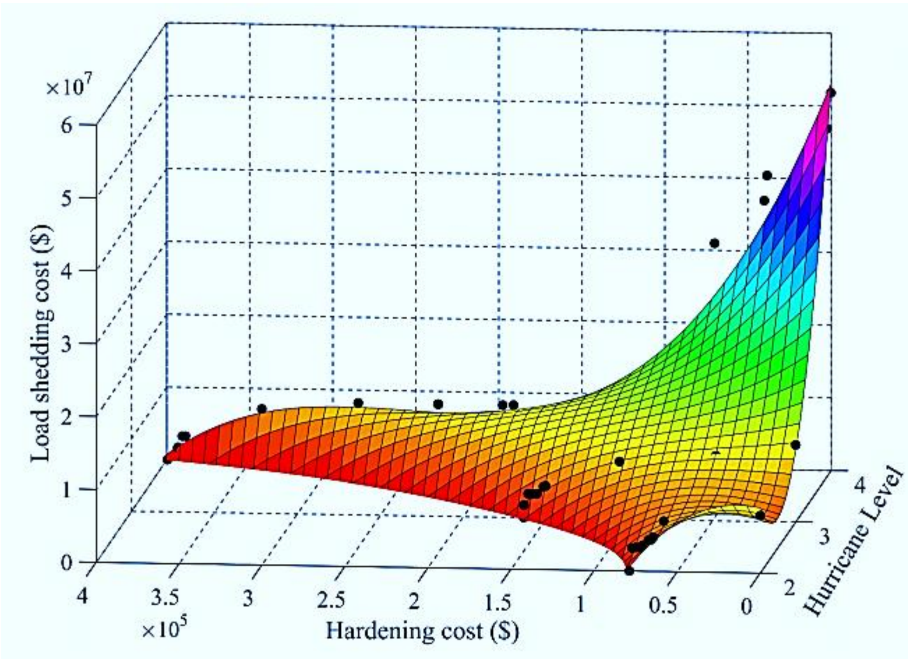

Fig 7: Coupled SPDS-SGT costs for different system resilience development resources and extreme weather event

(iv) Case study of larger coupled system

Table 3: DG placement vs load shedding cost and travel cost

DG placement Budget	UTS	PDS	BPDS	IEVC	SUEM	SPDS
1	8	7.9	7.8	7.7	7.5	7.2
2	6.1	6.9	5.9	6.3	6.2	6.1
3	5.3	5.8	4.9	4.5	5	5.1
4	4	3.1	3	3.2	3.1	3
5	2.9	2.7	2.6	2.4	2.8	2

The efficiency of DGplacement and line hardening and is represented numerically in the table.3. Further the in Fig. 8(a) & 8(b) the higher coupled framework, the marginal applications of DGplacement and line hardening minimize as enhance the respective budgets. In comparison with the DG placement, line hardening performance is good, but costs are high. The graphical figure represents an efficient towards obtaining correct budgets for DG placement and line hardening alternatives in relation to the assessment of extreme weather event classification and the appropriate stage of resilience system.

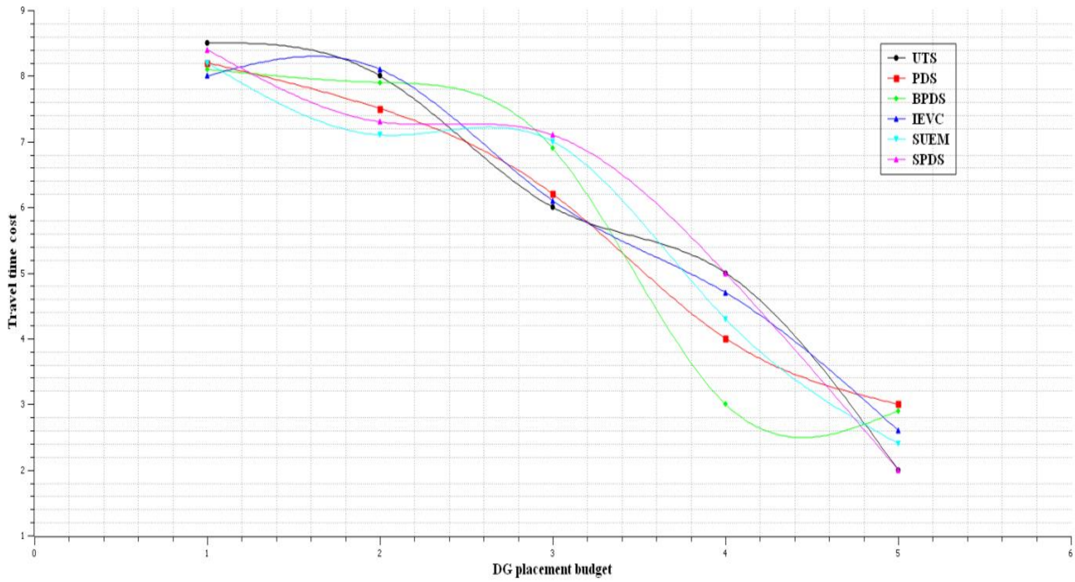

Fig 8(b): influence of DG placement on the resilience of higher coupled SPDS-SGT

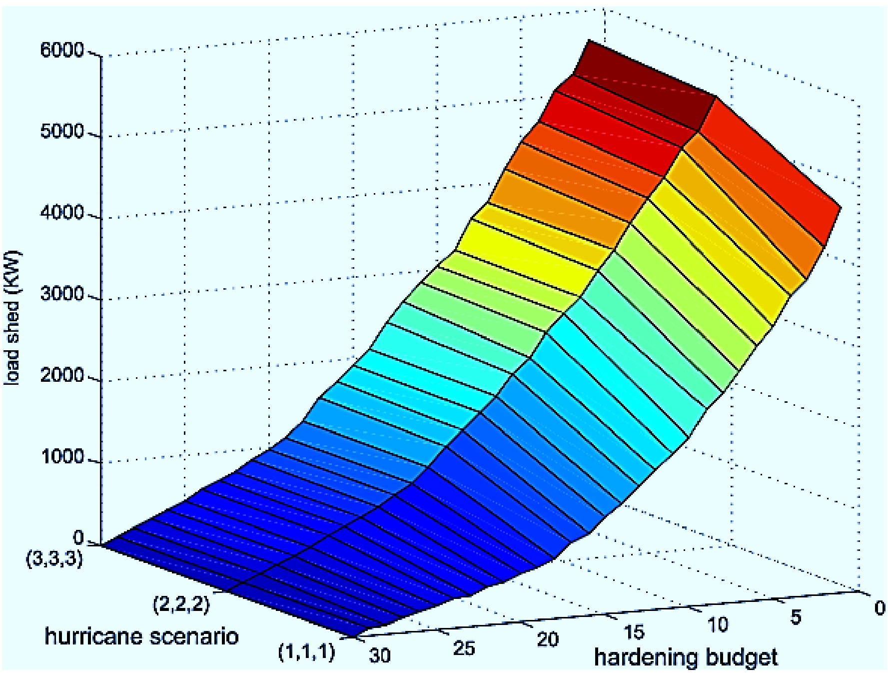

Fig 8(b):Total cost for differnt line hardening resources and extreme weather events in higher coupled SPDS-SGT

The proposed SPDS-SGT tri-stage optimization system can be further increased to the site and scale of new DGs and battery swapping method, on-road charging stations for electric vehicles and more withstandable for extreme weather conditions. The coupled SPDS-SGT is examined as two decoupled framework. Here, the equivalent bi-level model transformed from the tri-level method via Karush -Kuhn-Tucker (KKT) has been resolved using a greedy search approach in the conventional techniques. The experimental results show that the effectiveness of the proposed system using case studies with a relevant method for coupled SPDS-SGT has shown prominent outcomes.

4. Conclusion

This paper presents, the development of resilience strategy in extreme weather events for power distribution network coupled with the smart green transportation in the smart city over extreme weather events. This method gives optimal strategies for DG placement and line hardening to enhance the resilience of SPDS and SGT. A tri-stage optimization model has been proposed to resolve the proposed issue. The first stage resolves the system resilience development issue, and the next stage models the coupled PDS-UTS actions through the hard extreme weather event case. The final stage resolves the problem of ideal load shedding in SPDS and the DEU problem in SGT. Experimental results verify the performance of the proposed framework in reducing the coupled SPDS-SGTexposure to extreme weather events. In Comparison with previous impacts on hardening of power system, the proposed approach is high resilient it examines the interaction of main SGT and SPDS framework in the maximization of DG placement and line hardening options.

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