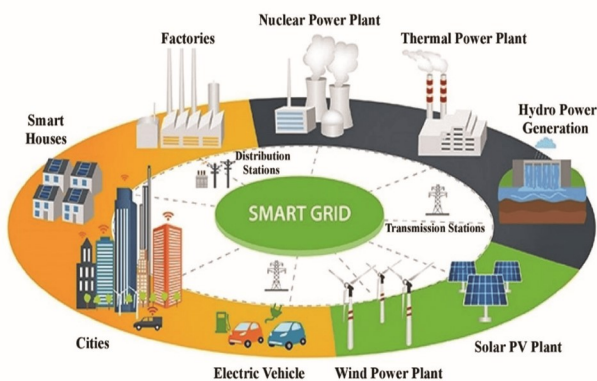
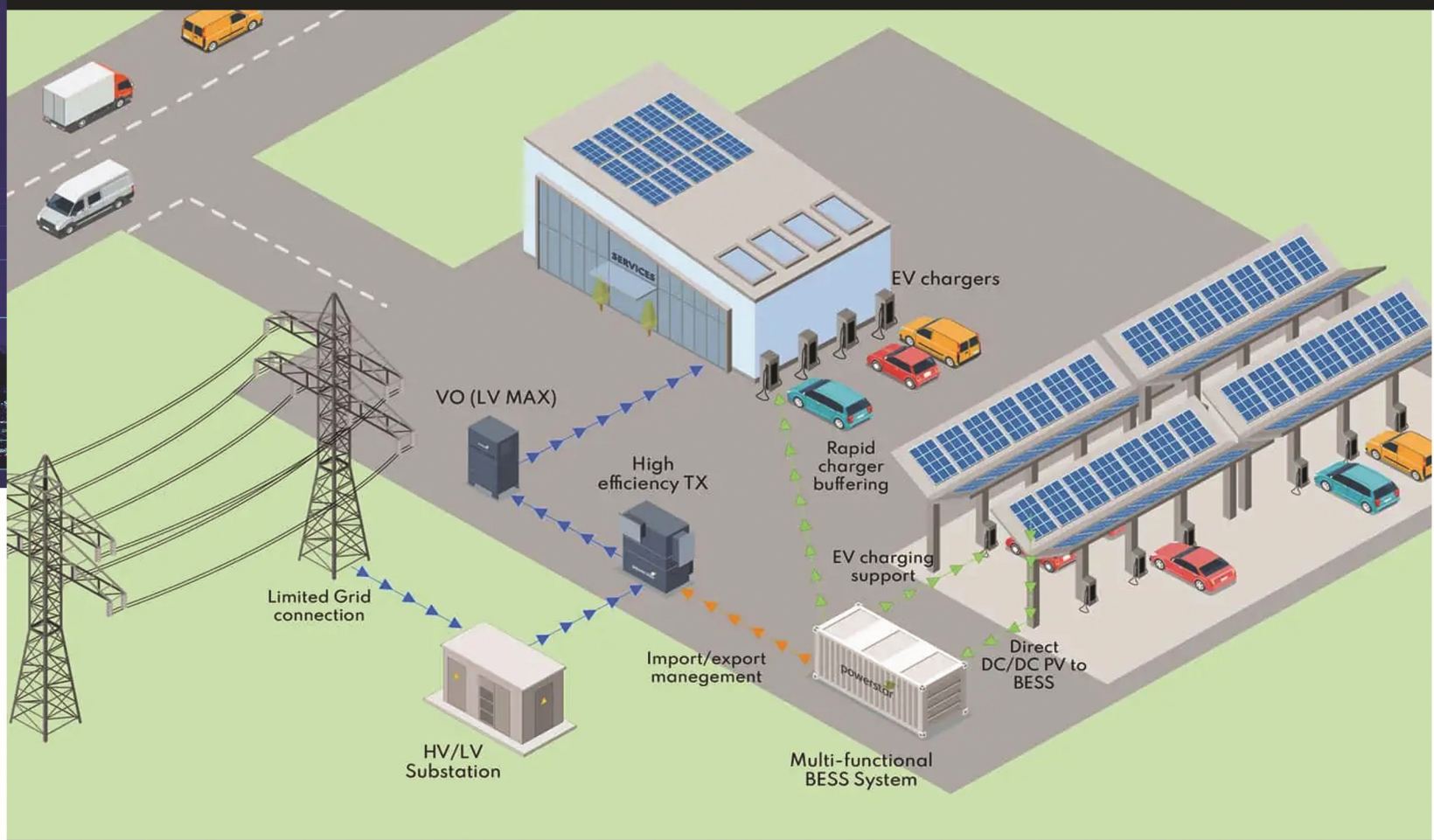


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Editorial...

Technology Development Prospects for The Indian Power Sector

India is one of the fastest growing economies in the world and is emerging as a global leader in addressing climate and clean energy challenges. The global economy is set to grow four fold in the next 40 years, which promises economic benefits and huge improvements in people's standard of living. But it also implies a much greater use of energy. A global revolution is needed in the ways that energy is produced, supplied and used.

We see an unprecedented increase in demand for energy and diminishing supplies of fossil fuels, increased complexities in the distribution system and emergence of prosumers. This demands the need to increase renewable energy source, build robust, reliable and well-organized infrastructure

The technical challenges of the electricity sector in India include low efficiencies of thermal powerplants, continued reliance on coal plants, and inadequate transmission and distribution networks both in infrastructure and integration of new technologies.

Improving the efficiency of electricity generation from coal is needed to exploit the extensive domestic coal resources and reduce air pollution. Integrated gasification combined cycle (IGCC) technology could achieve this. We require more liquefied natural gas (LNG) terminals and gas pipelines, and deployment of natural gas combined cycle (NGCC) power plants. Low carbon generation options, and Retrofitting coal power plants with CO₂ capture are also suggested.

Thorium based reactors and light water reactors can be an alternative strategy for India's nuclear future. The combination of photovoltaic (PV) and concentrated solar power (CSP) can contribute significantly to fulfilling the country's electricity demand.

India has enough hydropotential to meet the demand especially in the north eastern states, but will require new evacuation provisions to the load centres.

The following area in transmission, system operation and distribution also should be addressed with priority to get the benefits of technology proliferation namely reduction in AT&C losses with network upgradation, reduction in theft, improved metering, billing and collection automation, better monitoring supervision and control, etc. and other key areas include the Advanced Distribution Management System and Information communications technology, advanced metering infrastructure, cyber security, power quality forecasting system coordination, market facilitation, cyber security, integrated network planning, scheduling and despatch, human resource and skill requirement.

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- *Thou shalt maintain thy integrity under all circumstances.*
- *Thou shalt incessantly work for the advancement of the professional knowledge.*
- *Thou shalt not give an incorrect professional opinion*
- *Remember Thou art a member of a team and the achievement of the team is thy own success.*
- *Thou shalt not malign thy co-professionals.*
- *Thou shalt strive for the advancement and dignity of thy juniors in the profession.*
- *Thou shalt strive for the welfare of the community.*
- *Thou shalt enlighten the community with the correct aspect of Engineering/Technological activities.*
- *Thou shalt endeavour to develop a dignified status in the society.*
- *Thou shalt strive by conduct and character to be a worthy citizen of the Motherland.*

Power Flow Solutions Allied Algorithm for Optimum Placing and Sizing of Distributed Generation of Renewable Energy Sources and Congestion Management in Transmission Network

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Abstract—The energy supply entities widely adopt distributed generators (DG) to meet the additional power requirement due to scheduled or unscheduled interruptions. The expansion of transmission and distribution systems via the inclusion of loads and generators and the occurrence of line interruptions are significant causes of congestion of transmission lines in interconnected systems. The management and alleviation of congested lines is a primary requirement for a power system network's reliable and efficient operation. The researchers investigated the potential scope of distributed generation (DG) to alleviate the congested branches in interconnected transmission systems. The development of a reliable scheme to arrive at the best location and size of local generators for alleviating congestion deserves considerable importance. This paper attempted to develop a simple and reliable strategy for the optimum placement and sizing of DGs to be integrated with a transmission line system of DGs for congestion relief in transmission lines by analyzing power flow solutions. This research work considered the 14-bus system of IEEE for the preliminary analysis to identify the parameters employed for assessing the severity of line congestion and the best placement and sizing of DGs for congestion relief. This work analyzed power flows by load flow algorithms using ETAP software in the 14-bus IEEE system for different line outage cases. The analysis of power flow solutions of the 14-bus system

of IEEE revealed that the percentage violation of the system can be regarded as an essential parameter to assess the extent of congestion in an interconnected system. A detailed power flow analysis of the system with various capacities of DG integration at several buses in the system revealed the application of two indices, namely the index of severity (SI) and sensitivity factor (SF), for optimum placement with the best capacity of DGs for congestion alleviation in the system. This work proposed a reliable algorithm for the best siting and sizing of DGs for congestion relief by using the identified indices. The proposed methodology is system indices allied load flow-based algorithm. This work produced a fast simulation solution without any mismatch through this developed scheme. The approximations linked with the algorithm were very minute, resulting in comprehensive bests instead of inexact limited bests with less simulation time and more convergence probability and availing the benefits of the mathematical approach. The work investigated the feasibility of the proposed methodology for optimum placing and quantifying DGs for congestion solutions for a practical interconnected bus system in the supply entity of the Kerala grid with many buses. Any transmission system operator can adopt this method in similar connected systems anywhere. The proposed algorithm determined the most severe cases of congestion and the optimum site and size of DGs for managing congested feeders in the grid system. The

analysis of the losses in the system for different cases of DG penetration by load flow analysis validated the suitability of the obtained results.

Index Terms— Congestion management; Distributed Generation; Severity index; Power flow solutions based algorithm, Sensitivity factor, : interconnected transmission system.

I Introduction

The power system network grew significantly in recent years, owing to the ever-increasing demand. The power system network grew significantly in recent years, owing to the ever-increasing demand of industrial and commercial consumers all around the globe. It is essential to maintain reliability, security, redundancy and safety in delivering power to consumers, and it has a massive impact on the economic aspects of society [1]. One of the significant issues in the power system is the occurrence of congestion in transmission lines, which causes adverse implications in maintaining an acceptable level of system security and reliability. Power flow obstruction arises primarily due to improper network expansion, system abnormalities or heavy changes in the loading levels of the system [2]. Abnormal conditions of the power system trigger line congestions and endanger the power flow above the thermal limits of the transmission lines. Some of such abnormal conditions include the unscheduled outage of transmission lines during operational malfunctions, lightning strikes or natural disasters due to unexpected weather events, scheduled outages during preventive maintenance or long-term shutdown maintenance of heavy equipment and the severe impact of low-frequency events [3]. Another major cause of line congestion is the rise in power flow above its allowable range of thermal capacity of transmission lines as the utility generates and transmits more electricity to meet the increased load demand of the consumers.

Moreover, the consideration of economic factors motivates the utilities in deregulated systems to deliver more power for increased benefits, and it may lead to an overflow of energy in some transmission lines leading to congestion which is less likely to occur in the case of regulated systems. The literature survey revealed various impacts of transmission line congestion, such as excessive loading of the system components, failure to fulfil the demand of regional loads and the chance of

short-term black-outs in the system. Congestion may also lead to an outage of transmission lines leading to interruption of power delivery to consumers, adversely affecting the reliability and security of the system. The customers may also be affected by economic burden due to line congestion, especially in deregulated scenarios, as they may be required to pay more bills in case of electric power utilization in congested regions of the power grid. This situation demands the formulation of effective congestion management strategies to overcome the adverse effects of line congestion in interconnected transmission systems [4,5].

The credibility of the interconnected transmission system network can be improved when the power system specialist ensures congestion solutions in a fast, economical and efficient manner. One of the basic schemes is to optimize the scheduling of generators in the system such that the TSO controls power flow to reduce the congested lines, so that it does not exceed the thermal limits of the line. The literature survey revealed the adoption of various algorithms such as the Big Bang-Big Crunch (BB-BC) algorithm, the improved version of the particle swarm optimization (PSO) method in the form of hybrid BB-BC(HBB-BC) optimization algorithm, black-hole, meta-heuristic satin bowerbird, strength pareto evolutionary algorithm, artificial bee colony and multi-objective glow-worm swarm method and Harris hawks optimization algorithm for optimum rescheduling of generating stations for congestion relief in power system network [6]. Previous researchers proposed different algorithms for solving congested lines by rescheduling generators at central stations. The need to introduce changes in generation at significant stations and curtailment of loads creates additional revenue loss and complexity in its realization at inter-connected transmission systems. The generation scheduling approach is less preferred for congestion relief due to economic considerations. Variations in generator power outputs may lead to a restructuring of financial aids among generating companies and consequent economic revenue loss.

Another scheme for congestion relief is the integration of flexible AC transmission (FACTS) devices such as static voltage controllers (SVC), thyristor controlled rectifiers (TCR), thyristor switched capacitors and thyristor controlled rectifiers (TSC-TCR) along with

rescheduling of generators in the system [7–11]. The FACTS devices provide the required reactive power to loads locally, which avoids energy extraction from central generators through distant lines up to a certain level, and it assists in alleviating the congestion of transmission lines in the system. However, this method exhibits certain demerits such as the requirement of expensive FACTS devices, limits in the capacity of FACTS device integration due to loading limits of the system and provision of complex control and switching strategies for FACTS devices, the requirement of continuous monitoring schemes of FACTS devices for its smooth and fast operation [12]. The demand response (DR) technique for congestion relief controls power flow along congested lines by effectively controlling consumer load demand during congested periods. The DR technique ensures the customers' involvement in congestion relief of the system by rescheduling their consumption period from peak hours to off-peak hours, which helps the utility to adjust their load pattern by cutting the peak and filling the valley scenario to manage the congestion issue [13]. However, the overall power market and increase in system complexity introduce significant difficulty in the practical realization of the DR technique due to the requirement of advanced forecasting technology, communication methods, load monitoring methods and demand control strategies for congestion relief. Previous researchers investigated energy storage technologies and their benefits to enhance the transmission aspects of capabilities of congested transmission networks. Still, the battery storage used to alleviate thermal constraints has not yet been thoroughly ensured [14].

The demerits of generation scheduling technique, FACTS device integration methods, DR technique and energy storage technologies motivated the authors of this study to investigate the scope of another major scheme which utilized different DG methodologies such as renewable generation (solar and wind) and the use of alternative methods such as gas operated turbines, IC engines and diesel engines, which can also be adapted for congestion management [15,16]. Renewable distributed generation is a dependable scheme for alleviating congested transmission lines due to its economic and technical benefits. Various system constraints such as line loss reduction, voltage profile and resilience were addressed and analyzed for better performance [17]. The optimal siting and sizing of DG units supported the system to reduce power loss and

improve voltage profile and voltage stability fluctuation. Its outcome was illustrated profoundly in the reference [18]. This work conducted voltage performance analysis for high-penetration photovoltaic distribution systems, providing results for improving the system performance [19]. Improvement in power system resiliency was analyzed with optimal location and placing multiple DGs for evaluating the system's performance [20]. Congestion alleviation methodologies for steel mill power systems by distributed generation and DG allocation techniques in primary Distribution networks were analyzed and illustrated in depth in the reference [21,22].

The DG sources installed at the load buses will deliver the required active power to the loads in the system, reducing energy extraction from central generators through transmission lines over the long corridor. This scheme gives an insight into realizing effective strategies for alleviating congestion in transmission lines by DG penetration in the power grid. The DG integration scheme offers merits such as flexibility to supply the required power to loads with minimum cost and non-requirement of change in the scheduling of central generators locally [23]. The DG integration technology may not instruct the additional support of FACTS device integration or load-shedding scenarios as a solution for congested transmission lines. Researchers considered DGs an effective tool for congestion alleviation, meeting power loss minimization and operational objectives of system availability enhancement.

The outage of any one of the transmission lines may trigger other interconnected lines into a stage of overloading. Thus, installing DGs as a solution for congested lines should consider the level of overloading at each line, as the congestion severity relies primarily on the extent and area of the line outage and the system conditions. Integrating DG into the bus will change system parameters, such as values of active and reactive power flows along lines, power loss at lines, bus voltages and currents. The effectiveness of this method relies on the optimum placement of DG units with sufficient power injection capability at an optimal point in the congested system by considering the changes in the power flow, which will ensure the injection of the required amount of power for congestion relief in the system. Thus, it is essential to consider the changes in all the system parameters after the line outage concerning the normal system parameters just before

the integration of DGs into the system for congestion relief.

Developing methods for adequate sizing and siting of DGs for congestion relief requires estimating various parameters in the power system network. Such parameters include active and reactive power flows at each line, the magnitude of current at each bar, active and reactive power losses at each line and voltage magnitudes at buses during typical and outage cases with post- and pre-penetration of DGs in the system. Various techniques to determine the capacity and location of DGs integration into the system for effectively alleviating congestion in transmission lines by maintaining different system parameters within their allowable limits were proposed by previous researchers [23–25]. The previous studies broadly categorized the methods adopted for optimal allocation of DGs for congestion relief as analytical, optimization techniques, heuristic approaches and various miscellaneous techniques such as the clustering approach, the Monte-Carlo simulation, simulated annealing algorithm and the cuckoo search algorithm [26–30].

Heuristic methods include genetic algorithms (GA), ant colony optimization, simulated annealing, tabu search (TS), particle swarm optimization, the artificial bee colony algorithm, the shuffled bat algorithm, GA with point estimate method, modified simulated annealing and harmony search with the differential operator. Population-based heuristic methods were widely adapted in operational and planning studies because they efficiently handled multiple constraint criteria. The researcher detailed the use of heuristic methods for optimal siting and sizing of DGs in radial distribution networks [31,32]. The complexity in nature and ample time for computations are some of the demerits of the heuristics approach for optimization. The difficulties employed in heuristic and optimization algorithms motivated the authors to investigate the scope of application of the multi-index-based simulation technique of the load flow estimation approach. This strategy will allow for the evolution of a feasible scheme for the best placing and quantifying of DGs in interconnected transmission systems. The literature survey revealed that the analytical methods used mathematical models of the system to obtain the optimum solution for DG allocation. Primary analytical procedures described in the literature

for optimal allocation of DGs in a system have several bases, such as several eigenvalue evaluations, modal analysis, index, sensitivity-based and point estimation methods. Analytical methods face challenges in their application for large and complex power system networks due to the difficulty in obtaining mathematical functions for finding optimal location and capacity. However, the load flow calculation methods such as the Gauss–Seidel method and Newton–Raphson method are reliable mathematical methods to determine the power flows and voltage profiles at each area in a power system network.

As long as the power system planning considers operating the system under the N-1 criterion, the power grid shall be capable of facing an outage of a single transmission line, cable, transformer or generator without causing power interruption to any feeding area of the transmission system operator (TSO). The basic principle of N-1 security in network planning states that network security shall be ensured if a component, such as a transmission line, transformer or generator failure, occurs in a network operating at the maximum energy forecast levels if the system is designed to work under the N-1 criterion. In that case, these criteria will help to ensure system security, reliability, redundancy and safety throughout the system from downstream to upstream. N-1 criterion is the rule according to which the elements remaining in operation within a transmission system operator (TSO)'s control area after the occurrence of a contingency is capable of accommodating the new operational situation without violating operating security limits of the network.

The power system requires only N-1 lines or equipment to deliver the allocated power to all end users satisfactorily during normal system conditions. If one of the lines or equipment fails in the system at any time, the line or equipment will ensure system security, reliability, redundancy and safety throughout the system from downstream to upstream under the N-1 criterion.

This additional installation of one component is essential in generation expansion plan, transmission expansion plan and distribution expansion plan to operate the system under N-1 scenario. Renewable energy sources are available from kW to several thousands of MW, and renewable energy sources can be penetrated in any level of voltage of the system from downstream

to upstream. Due to the power quality issues created beyond the allowable range of parameters, such as voltage fluctuation, power factor variation, voltage stability, VAR compensation issues and frequency fluctuations, DGs cannot be considered a permanent remedial measure for N-1 contingency. However, the combined use of system indices, the fast power flow solutions and the investigated scheme's reliability will motivate the power system specialists to handle this methodology to a certain extent with loss minimization criterion. Renewable energy sources are widely used as distributed generation worldwide to a large extent. Several countries have substantial solar power plants with a capacity of 2200 MW or above extended across several thousands of acres of land in the deserts. Thus, the tremendous growth of renewable energy sources such as solar and wind energy systems triggered present power system policies and scenarios to a profound level of changes all over the globe.

This study proposes to formulate the system indices allied load flow-based algorithm to obtain the finest solution without any delay in achieving appropriate convergence availing the benefits of a mathematical approach. This work presented a load flow analysis-based method for congestion relief in a 14-bus system of IEEE. The objective of the analysis was to recognize the extremity of interruptions of transmission lines in the power system network. The work also attempted to identify the most critical cases of supply interruptions by analyzing load flow results. The research focused on identifying potential parameters to arrive at the best capacity and bus for DG integration for the solution of congested lines in the system as part of congestion management. This work analyzed power flows in the developed 14-bus IEEE system during line outage events by injecting DG sources of different capacities at several locations. This will help to recognize suitable parameters to propose a reliable scheme to find feasible buses and the capacity of DG to integrate into the system for congestion relief. The analysis focused on selecting the best case of DG penetration, which resulted in a maximum reduction in system loss. This work recognized two system indices to formulate a methodology to best place and quantify the DGs of an interconnected transmission system. This work investigated the applicability of these indices for optimum siting and sizing of distributed generation to inject into the system for

congestion relief. As a case study, the research successfully tested the part of the practical system of the supply entity of the state of Kerala, India, using the developed algorithm.

II FORMULATION OF MATHEMATICAL PROBLEMS

Outages of transmission and distribution lines are a critical source of congestion in a power system network, and more investigations on the same are necessary to ensure the feasible and steady operation of the network. Congestion occurs mainly due to the interruptions of feeders and transformers in the power system network. The impact of outages shall be recognized based on the percentage increase in power flow along the lines and are dependent on the area of the line outage and the transmission network configurations. A detailed study of the 14-bus system of the IEEE environment during the interruption of lines at various branches of the system must be conducted to understand the most severe case of line outage, which results in the most congested system conditions in the network. This study is also essential to identify the power flows along the lines for each case of line interruption in the system. As discussed in the previous literature studies, DG penetration is widely recognized as the most feasible scheme for alleviating congestion in the power system network with the following constraints.

$$V_{i,min} \leq V_i(u) \leq V_{i,max} \quad i \in B_s \quad (1)$$

where $V_i(u)$ is the voltage at bus i ; u is the set of control variables; $V_{i,min}$ and $V_{i,max}$ are, respectively, the minimum and maximum allowable voltages at bus i ; and B_s is the set of all buses.

Since the power flows through those feeder lines and tie switches cannot exceed their corresponding installation capacities, these limitations can be generally expressed as

$$P_l(u) \leq P_{l,max} \quad l \in L_s \quad (2)$$

where $P_l(u)$ and $P_{l,max}$ are, respectively, the power flow and the maximum allowable power of line l and L_s is the set of all transmission lines.

In addition to the operational bus voltage and line power flow constraints, the power that can be transferred by the individual tie switch is limited by the available transfer capability (ATC) as

$$P_l(u) \leq ATC_l \quad (3)$$

where ATC_l is the remained transfer capability in line l for further activity in addition to those already committed, and

$$ATC_l = TTC_l - TRM_l \quad (4)$$

where TTC_l is the maximum power flow without causing thermal overloads, voltage constraints, or any other system security problem at line l , whereas TRM_l is the reserved capability at line l comprising possible uncertainties due to system operational condition changes and contingencies.

When we analyzed the optimal power flow (OPF) scenario, several control variables were incorporated, such as generator voltage, transformer tap position, switched capacitor settings, reactive injection for a static VAR compensator, load shedding and decoupled line comprising possible uncertainties due to system operational condition changes and contingencies. When we analyzed the optimal power flow (OPF) scenario, several control variables were incorporated, such as generator voltage, transformer tap position, switched capacitor

$MVA_{ij} \leq MVA_{ij} \text{ (with line NM Out)} \leq MVA_{ij}$ (5)
settings, reactive injection for a static VAR compensator, load shedding and decoupled line where MVA_{ij} is the apparent power flow along the line connecting bus i and bus j with line nm out

$$P_{gen} - P_{load} - P_{loss} = 0 \quad (6)$$

where P_{gen} , P_{load} , P_{loss} are the total power generated by the generators, total load connected to the system and total system loss, respectively.

$$MVA \text{ Flow}_{nm} \leq MVA \text{ Flow}_{nm}^{\max} \quad (7)$$

where $MVA \text{ Flow}_{nm}$ is the maximum power flow without causing thermal overloads, voltage constraints or any other system security.

$$MVA \text{ Flow} + \sum_n \left(\frac{\partial}{\partial u} MVA \text{ Flow}_{nm} \right) \Delta u \leq MVA_{nm}^{\max} \quad (8)$$

where $MVA \text{ Flow}_{nm}$ is the maximum power flow without causing thermal overloads,

$$P_1 + P_2 + \dots + P_{ref} = P_{load} \quad (9)$$

where each P represents the generator power, load and loss in MW.

As reported in the literature, the congestion issues shall be alleviated, and other problems which occur during line congestion, such as an increase in power loss, and reduced reliability in system performance, shall also be rectified by integrating DGs. In addition, the advantages of achieving stability and bus voltage reliability of the system shall be fulfilled. Furthermore, the research studies are essential to propose a reliable scheme to determine the optimal size and capacity of the settings, reactive injection for a static VAR compensator, load shedding and decoupled line flow. The OPF is a very lengthy and very tough mathematical programming problem. The OPF equations can be expressed in terms of a vector of state variables x , vector of control variable u , and vector of fixed parameters p . The associated OPF equations using various methods were obtained as detailed below [33,34].

DG, which is to penetrate the system to reduce power loss in an extensive power system network. This demands the estimation and analysis of power flows during line outages and the integration of DGs into the system during outage cases. An intense study of power flows and associated index parameters of the system during the integration of DG's various capacities is a necessary task in the formulation of a suitable scheme for finding the feasible location and capacity of DG to be integrated into the system during the outage of a line in the system for congestion relief.

The application of two parameters, namely the Index of Severity (SI) and distributed generation sensitivity factor (SF), is described in this paper for estimating the range of congested lines and finding the best DG placement in the system for alleviating the congestion during the case of a line outage in the system. The definition of the proposed index parameters is described below.

Severity Index and Percentage violation of loading

The severity index estimated using active power flow along transmission lines used to find out the worst outage case and to alleviate the congestion in transmission lines were described in [33,34]. In this paper, the parameter known as the severity index (SI), estimated using

apparent power, is proposed to identify the severity of line outages in the system. It is a dimensionless parameter and is given by,

$$SI = \sum_{\substack{\text{all branches} \\ 1}} \left[\frac{S_{\text{flow}l}}{S_{\text{lmax}}} \right]^{2n} \quad (10)$$

where the SI severity index will provide the extent of the outage affecting the power system. SI will be small if all flows are within the limit and large if one or more lines are overloaded. The best value for n is identified as 1 or 5 to obtain sufficient information in the solution at the end of the first iteration of the decoupled power flow to obtain favourable SI [34,35].

Percentage violation of loading is calculated as given in (11).

$$\text{Violation} = \frac{THL - PRL}{THL} \times 100 \quad (11)$$

where *THL* is the thermal limit and *PRL* is the present load in the transmission line.

As long as the voltage is incorporated in the SI, the equation will be interpreted as a severity index estimated using apparent power flow along transmission lines, which is used to find out the worst outage case and alleviate the congestion in transmission lines given by (12).

$$SI = \sum_{\substack{\text{all branches} \\ l}} \left(\frac{S_{\text{flow}l}}{S_{\text{lmax}_l}} \right)^{2n} + \sum_{\substack{\text{all buses} \\ i}} \left(\frac{\Delta |E_i|}{\Delta |E|_{\text{max}}} \right)^{2m} \quad (12)$$

(b) Sensitivity Factor

Here, the sensitivity factor is estimated between line *l* and generator bus *i* when line *k* is an outage. $\Delta |E_i|$ The difference between the voltage magnitude as solved at outage and base case voltage magnitude. When addressing the bus phase angles $\Delta \theta$ for the obtained set of changes in the bus power injections, *P* the following mathematical equations will come into the picture using *a*, *d* and *d* factors to model the power system in its post-outage state

$$\Delta \theta = [X] \Delta P \quad (13)$$

where the bus phase angle change $\Delta \theta$ for the obtained set of changes in the bus power injections, ΔP

$$\Delta P = \begin{bmatrix} \vdots \\ \Delta P_n \\ \vdots \\ \Delta P_m \end{bmatrix} \quad (14)$$

$$\tilde{P}_{nm} = \Delta P_n = -\Delta P_m \quad (15)$$

$$\Delta f_k = a_{ki} \Delta P_i \quad (16)$$

where $(a_{li} + d_{l,k} a_{ki})$ is the compensated generation shift sensitivity factor

$$\Delta f_i = a_{ki} \Delta P_i + d_{l,k} a_{la} \Delta P_i = (a_{li} + d_{l,k} a_{ki}) \Delta P_i \quad (17)$$

The linear sensitivity factor can be expressed as partial derivatives, as in Equation (18). It demonstrates the flow's (MVA) sensitivity on Lines *i* to *j* concerning the power generated at bus *k*. linear sensitivity factor can be expressed as partial derivatives, as in Equation (18). It demonstrates the flow's (MVA) sensitivity on lines *i* to *j* concerning the power generated at bus *k*, where LSF is the linear sensitivity factor. The injection of DGs into the system alters the power flow at each line in the network. These mathematical equations support the finalization of an index known as distributed generation sensitivity factor (SF), which considered the relative change in apparent power flow along lines concerning the capacity of penetrated DGs and is defined as given in (18). The SF is obtained from the congested lines by power flow change in a transmission line' *l*', which connects the buses *n* and *m*. In this equation, the apparent flow of power is considered for the estimation of the DG sensitivity factor *SF* considering the influence of reactive power flow.

$$\text{LSF} = \frac{\partial \text{MVA flow}_{ij}}{\partial \text{MW gen}_{ik}} \quad (18)$$

$$SF = \frac{\delta S_i}{\delta P_i} \quad (19)$$

The severity index components of the branches (SICB) of the base system of the IEEE 14-Bus test system were arrived at using the

$$\text{equation SICB} = \left(\frac{S_{ij}}{S_{ij \max}} \right)^2$$

The values of the severity index component (SICB) of each branch from the power flow status were calculated and are presented in Table 1. From the values, it was observed that none of the SICBs was greater than 1 when there was no component outage in the system. Hence, there was no congestion in the base system, whose SI was 8.4, as presented in Table I. In observing the outage case in Table 1, the results indicate that the values of SICB for the lines L6_11, L10_11 and L12_13 as 1.61, 2.49 and 2.22, respectively. Hence, these lines were identified as congested lines due to the outage of L6_13. From the results, it was also inferred that line L10_11 was the most critically crowded compared to lines L6_11 and L12_13.

Repeated N-1 simulation studies were conducted using the ETAP® simulation for the outage of each component, such as the transmission line, transformer and generator, to observe the congestion by carrying out an N-1 analysis. The number of congested lines and SI obtained for the entire simulation study are given in Table II. The outage branches such as generator, transformer and line number, consequent number of congested units and respective SI index values were obtained. In the normally running base system of the 14-bus IEEE system as configured in Fig 1, the value of SI = 8.4. Table 2 shows that all outage branches in Figure 1 with SI values above 8.4 were treated as congested cases in the system with N-1 analysis, and the number of congested lines in each outage case also showed the importance of the analysis. Being SI a Global

Index, in principle it is possible to have congestion cases in which SI is lower than 8.4 in other systems depending upon the configuration of the components. Similarly, the choice of the cases with SI higher than 8.4 is not intended to represent all the possible congestion cases of other systems and it depends upon the components configuration of the system.

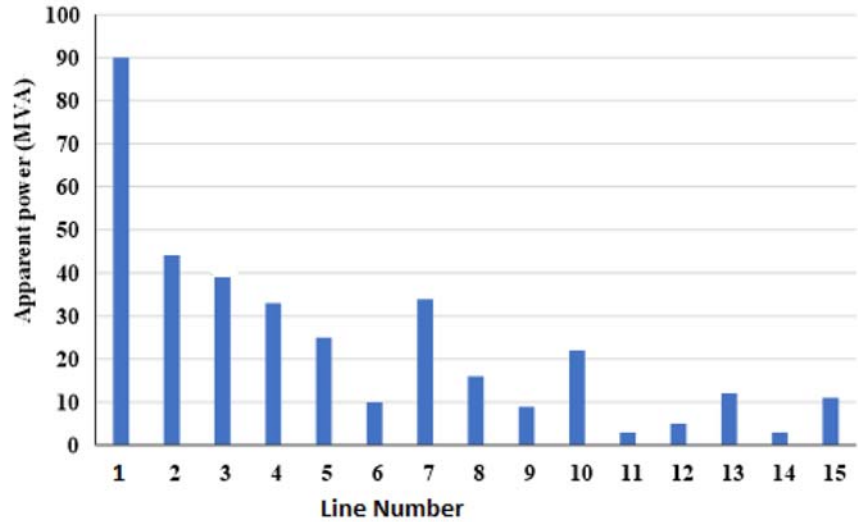


Fig2 A Typical load capability profile is considered for load flow analysis under normal conditions for the 14-bus system of IEEE of IEEE 14 Bus System

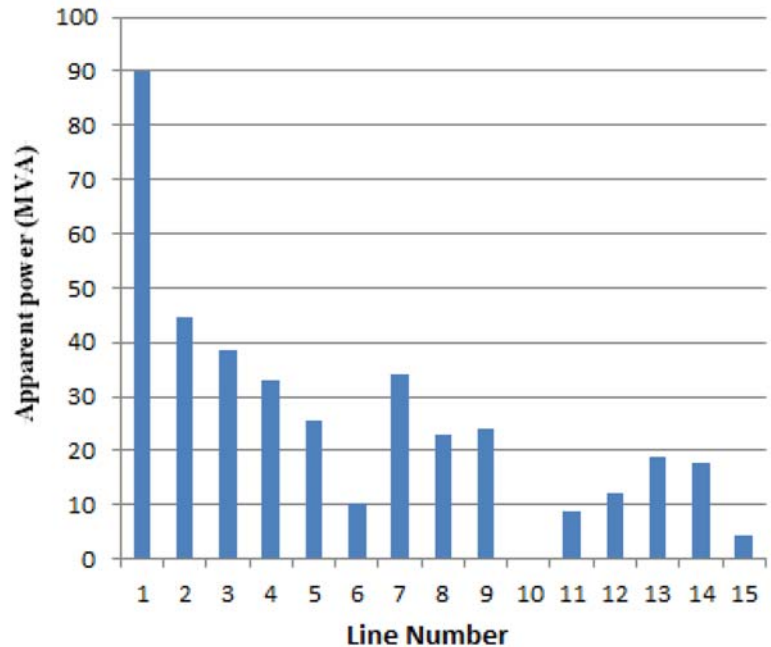


Fig.3 . A typical load profile under outage of Line 10 by load flow analysis for the 14-bus system of IEEE

TABLE I SICBS, SI AND VIOLATION PERCENTAGE TABULATION OF MODIFIED IEEE 14-BUS SYSTEM WITHOUT OUTAGE AND OUTAGE OF LINE 6-13 CASES (N-1 ANALYSIS).

Branch	Line Number	Load Flow without Any Outage			Load Flow with L6_13 Outage		
		S_{ij} in MVA	SICB = SQ ($S_{ij}/S_{ij,max}$)	Violation%	S_{ij} in MVA	SICB = SQ ($S_{ij}/S_{ij,max}$)	Violation %
L1_2	1	90.0	0.6	-25.1	89.94	0.56	-25.04
L1_5	2	44.0	0.5	-31.6	44.45	0.46	-31.61
L2_3	3	39.0	0.4	-40.4	38.75	0.35	-40.38
L2_4	4	33.0	0.3	-49.2	33.05	0.25	-49.14
L2_5	5	25.0	0.3	-49.2	25.39	0.25	-49.20
L3_4	6	10.0	0.0	-84.2	10.27	0.02	-84.20
L4_5	7	34.0	0.6	-24.5	34.02	0.57	-24.38
L6_11	8	16.0	0.8	-12.8	22.87	1.61	27.06
L6_12	9	9.0	0.1	-72.0	24.21	0.57	-24.32
L6_13	10	22.0	0.5	-30.0	0	0	-100.00
L9_10	11	3.0	0.0	-90.3	8.66	0.07	-72.91
L9_14	12	5.0	0.0	-84.6	12.15	0.14	-62.01
L10_11	13	12.0	1.0	-1.7	18.93	2.49	57.83
L12_13	14	3.0	0.0	-78.0	17.90	2.22	49.17
L13_14	15	11.0	0.8	-9.3	4.1821	0.12	-65.14
SI = 8.4, No Congestion. SI = 12.5 System under Congestion							

TABLE II NUMBER OF CONGESTED LINES AND SEVERITY INDEX (SI) FOR VARIOUS OUTAGE CASES IN THE MODIFIED IEEE 14-BUS SYSTEM

Outage Branch L/G/T	Outage L/T/G Number	Total Number of Congested Lines	Severity Index (SI)
L1_2	1	2	13.7
L1_5	2	1	9.2
L2_3	3	1	10.3
L2_4	4	1	9.9
L2_5	5	0	8.13
L3_4	6	0	8.3
L4_5	7	0	8.2
L6_11	8	2	12.1
L6_12	9	1	9.1
L6_13	10	3	12.5
L9_10	11	1	8.5
L9_14	12	1	8.5
L10_11	13	1	10.3
L12_13	14	1	8.5
L13_14	15	2	11.6
G2	G2	0	8.92
G3	G3	1	10.70

G6	G6	2	9.70
G8	G8	3	9.98
T1	T1	6	20.85
T2	T2	3	10.00
T3	T3	3	12.01
T4	T4	3	9.98
T5	T5	4	17.21

The sensitivity factor (SF) determined the best bus location for the penetration of DG into the system for congestion management in transmission lines. Distributed generation SF for each case of DG penetration of 1 MW at different buses was determined from the load flow results obtained by simulation using ETAP software. It was regarded that the negative values of SF reflected the suitability of that location of the bus for DG placement for managing congestion in the interconnected transmission lines, as shown in Table . The investigation revealed that for the feeder outage (L6_13), the feasibility of all load bus locations of Bus No. 4, Bus No. 5, Bus No. 7, Bus No. 9, Bus No. 10, Bus No. 11, Bus No. 12, Bus No. 13 and Bus No. 14 were considered for managing congestion in the system, as displayed in Table 3. Thus, different scenarios for congestion relief were obtained by analyzing the system's power flow for the critical outage case (interruption of feeder L6_13) and the conditions for feasible placing and quantifying of DG integration were determined as given in Table III. The simulation results and power flow study in the power system network with penetration of DG revealed that the identified Bus No. 7, Bus No. 9, Bus No. 10 and Bus No. 14 were considered suitable buses for integration of DG sources during the outage of feeder L6_13; thus, DG Bus No. 7, DG Bus No. 9, DG Bus No. 10 and DG Bus No. 14 were treated as feasible buses as shown in Table III.

TABLE III SENSITIVITY FACTOR FOR 1 MW DG PLACED AT VARIOUS BUSES

Feeder L6_13 Open			
DG Bus	SF	SF	SF
	Feeder L6_11	Feeder L10_11	Feeder L12_13
Bus 4	0.000	0.000	0.000
Bus 5	0.000	0.000	0.000
Bus 7	-0.140	-0.150	-0.060
Bus 9	-0.320	-0.320	-0.130
Bus 10	-0.360	-0.360	-0.080
Bus 11	-0.470	0.460	0.020
Bus 12	0.200	0.200	0.300
Bus 13	0.030	0.030	-0.490
Bus 14	-0.170	-0.170	-0.290

IV CONGESTION MANAGEMENT TECHNIQUE FOR BEST DG CAPACITY

The power loss at each line is a critical factor to consider during integrating DGs at buses for congestion relief. It was considered in this work to determine the optimum size of the DG source to be integrated into the system for alleviation of congestion during the case of a line outage. The capacity of DG size, which, when injected into the system, results in minimum power loss, will have the capability to alleviate the congested feeders at the maximum level, and it shall be regarded as the best size for the local generator integration as shown in Table 4. The system power loss with various buses for DG penetration of appropriate capacity, which offers minimum power loss when injected at different buses, is shown in Table IV.

The solution for managing congested lines in the interconnected system was ensured by adopting DG methodology at the system of congestion with power loss minimization criteria utilizing the developed algorithm, and its reliability of optimum siting and sizing of DG was proved by cross-checking Tables III, IV & V.

TABLE IV DG CAPACITY AT ALL LOAD BUSES WITH POWER LOSS MINIMIZATION CRITERIA FOR THE 14-BUS SYSTEM OF IEEE.

DG Bus	DG Size in MW	Minimum Power Loss(MW)
Bus No. 4	70.00	0.051
Bus No. 5	65.00	0.055
Bus No. 7	55.00	0.049
Bus No. 9	55.00	0.038
Bus No. 10	45.00	0.046
Bus No. 11	3.000	0.063
Bus No. 12	25.00	0.067
Bus No. 13	30.00	0.049
Bus No. 14	35.00	0.041

TABLE V. OPTIMAL BUS AND DG SIZE FOR THE 14-BUS SYSTEM OF IEEE.

DG Bus	DG Size in MW
Bus No. 7	55.00
Bus No. 9	55.00
Bus No. 10	45.00
Bus No. 14	35.00

V PROPOSED ALGORITHM FOR MANAGING CONGESTED FEEDERS IN TRANSMISSION NETWORK

The most crucial step in the development of the algorithm is the design of the accurate power system model, as any error in the system data will adversely affect the simulation results of the actual model of the system to be investigated. The system data, such as resistance, inductance and capacitance of the transmission line, shall be collected and entered correctly to reflect the better performance of the system. It shall be measured and used appropriately. The length of the transmission line and its conductor material shall be considered seriously to obtain accurate simulation results. The transformer specifications, including tap positions, shall be precise while considering the transformer design, and the winding shall be connected with the correct polarity. The type of generators shall be entered explicitly for the appropriate result. The wrong selection of generators may cause a system mismatch while running the algorithm. Utmost care is required to simulate without mismatch. The algorithm's accuracy depends upon the safe data handling in the system. The identified sensitivity factor (SF) index can be employed to find the feasible location of DGs to be integrated into the system for congestion relief in transmission lines. Using SF in a congested line can minimize the effort to identify the feasible location for DG penetration in an extensive interconnected system. The combined use of load flow analysis and SF is detailed in this section. The combined effect can formulate a feasible approach for finding the best size and bus location for DG placing, thereby managing congested feeders in the transmission network.

The proposed algorithm for managing congested feeders in the transmission network during an outage of lines is described in Figure 4. The algorithm proposes the combined application of system knowledge and computer simulation-based load flow analysis of the system for managing congested feeders in the

transmission network. The power system expert shall acquire a prior understanding of the practical system's parameters for applying this algorithm. The developed system parameters shall be used to formulate a load flow model of the system. They can be utilized for assessing the severity level of various line outage cases and estimating the sensitivity factor (SF) for multiple capacities and the location of DG integration into the system for congestion management during outage cases. The proposed algorithm demands the analysis of power flow solutions of the practical system under various line outage cases and the estimation of congestion level in terms of the number of congested lines and severity index for each outage case. This knowledge shall be used to obtain prior knowledge of solutions for congestion relief by DG integration. Thus, by estimating the severity index during each outage case, the system expert will be able to assess the critical impact of a line outage case on the system during its occurrence.

The technical scheme for managing congested feeders in the transmission network during a particular line outage case requires the analysis of the power flow solutions of the developed model of the system with the corresponding outage introduced into the model. The computer-based simulation and analysis of power flow solutions will yield the apparent power flow and power loss at each inter-connected system's inter-connected lines. The obtained results shall be used to estimate the sensitivity factor (SF), which can be used to find the best bus for DG penetration for managing congested feeders in the transmission network in the corresponding line outage case. The buses which yield negative values of SF for DG integration in the buses shall be regarded as feasible buses for DG integration into the system for managing congested feeders in any IEEE bus system or any practical interconnected system of any entity.

The decisions of feasible buses using SF should be followed by a series of apparent power flow solutions for the study of the system with outage cases by integrating various capacities of DG sources into the system at feasible buses. During the case of DG integration of various capacities at each possible bus, the power loss in the system shall be acquired by simulation. It can be used to determine the best DG penetration bus for managing congested feeders in the transmission network. Integrating a feasible DG capacity

at each viable bus will ensure a congestion-free environment in transmission lines. These DG capacity values shall be obtained by power flow solutions of the system with DG penetration of various matters in the feasible buses. A detailed apparent power flow analysis will yield the DG source values, which tremendously diminish the obstruction of power flow identified by checking the system's severity index (SI). These values will be different at each feasible bus. Thus, the power flow analysis of the transmission network with variable DG capacity at the probable buses yields the DG capacity required at each viable bus for managing congested feeders in the transmission network. The next task for managing congested feeders in the transmission network with DG penetration is the most favorable selection among the feasible buses and DG capacities. This shall be acquired by the analysis of power loss of the system for each of the DG integration cases at workable buses. The power loss in the system with DG integration of derive values for congestion relief at the workable buses shall be estimated by load flow analysis. The combination of DG size and location, which yields the minimum power loss in the system, shall be regarded as the optimal size and site for DG or local generator integration for managing congested lines for the particular line outage case, as described in the proposed methodology in Figure 4. This scheme will provide advance information for the best capacity and location of the local generator to be integrated into the system by estimating the appropriate values of distributed generation sensitivity factor (DGSF). The formulated methodology will provide a proactive indication to arrive at the most

favourable buses to eliminate the power flow obstruction in the feeders of the transmission network by the allocation of appropriate local generators or DGs in any interconnected system, using the advanced collection of DGSF in the intermittent step itself of the algorithm rather than moving to the final stage of the scheme.

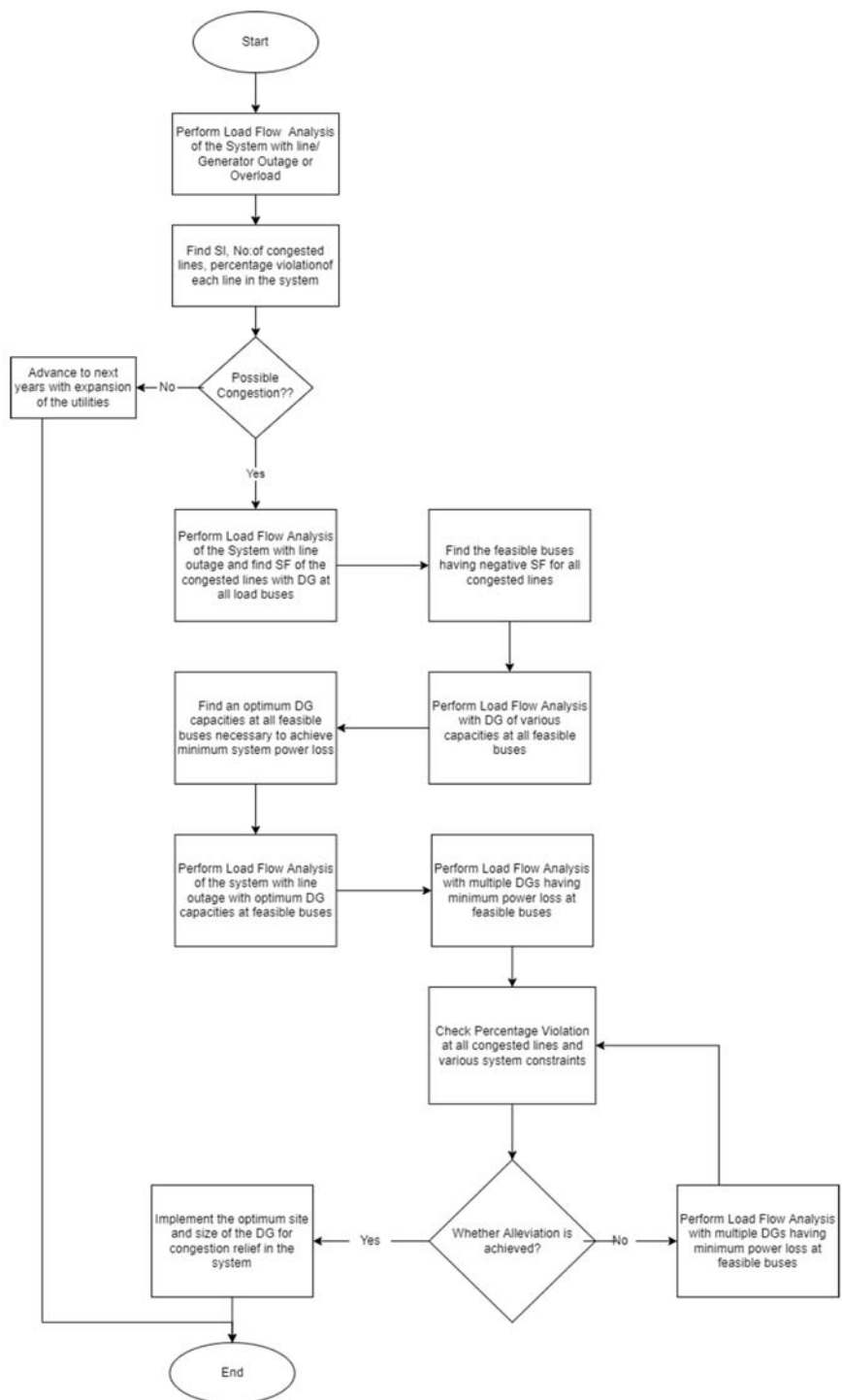


Fig.4 . A Algorithm for managing congested feeders in interconnected transmission networks of any bus system with DG penetration

VI VALIDATION OF THE PROPOSED ALGORITHM FOR MANAGING CONGESTED FEEDERS IN THE TRANSMISSION NETWORK OF THE 14-BUS SYSTEM

The load flow analysis for the system with DG at various load buses was conducted by simulation, and the results are given in Table VI

TABLE VI VALIDATION TABLE OF THE ALGORITHM WITH VARIOUS DG PENETRATION AT ALL LOAD BUSES OF THE 14-BUS SYSTEM OF IEEE

Bus4				Bus 5		Bus 7		Bus 9		Bus10		Bus11		Bus12		Bus13		Bus 14		
DG X (MW)	Y			X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	
1	0.07	17.9		0.07	17.9	0.07	18.03	0.06		17.76	0.06	17.76	0.07	18.03	0.07	17.76	10.06	17.76	0.06	17.76
5	0.06	17.98		0.06	17.98	0.06	18.24	0.06		16.90	0.06	16.90	0.06	16.91	0.06	16.91	0.06	16.90	0.06	16.90
10	0.06	17.97		0.06	17.97	0.06	18.34	0.06		15.99	0.06	16.00	0.06	16.01	0.06	16.01	0.05	15.99	0.05	15.99
15	0.06	17.96		0.06	17.97	0.06	18.44	0.05		15.26	0.05	15.27	0.06	15.29	0.06	15.28	0.05	15.27	0.05	15.26
20	0.06	17.96		0.06	17.96	0.05	19.96	0.05		14.71	0.05	14.71	0.06	14.74	0.06	14.73	0.05	14.71	0.04	14.70
25	0.06	17.95		0.06	17.06	0.05	20.85	0.05		14.32	0.05	14.33	0.06	14.36	0.06	14.36	0.05	14.33	0.04	14.32
30	0.05	17.94		0.06	17.95	0.05	21.91	0.04		14.10	0.05	14.11	0.06	14.155	0.06	14.15	0.04	14.12	0.04	14.10
35	0.05	17.94		0.06	17.95	0.05	23.13	0.04		14.05	0.04	14.06	0.06	14.11	0.07	14.11	0.05	14.08	0.04	14.05
40	0.05	17.98		0.05	17.94	0.05	24.53	0.04		14.17	0.04	14.18	0.06	14.23	0.07	14.24	0.05	14.20	0.04	14.17
45	0.05	17.93		0.05	17.94	0.05	26.12	0.04		14.40	0.04	14.45	0.06	14.53	0.08	14.53	0.05	14.49	0.04	14.46
48	0.05	17.93		0.05	17.94	0.05	27.80	0.04		14.42	0.04	14.46	0.06	14.67	0.08	14.69	0.05	14.57	0.04	14.72
49	0.05	17.93		0.05	17.94	0.05	27.88	0.03		14.45	0.04	14.47	0.06	14.78	0.08	14.97	0.056	14.68	0.04	14.81
50	0.05	17.92		0.05	17.93	0.05	27.89	0.03		14.90	0.04	14.92	0.06	14.98	0.08	15.00	0.05	14.96	0.04	14.92
55	0.05	17.92		0.05	17.93	0.04	29.85	0.03		15.52	0.04	15.54	0.07	15.61	0.09	15.63	0.05	14.49	0.04	15.54
60	0.05	17.92		0.05	17.93	0.04	32.01	0.03		16.31	0.04	16.33	0.07	16.41	0.09	16.43	0.06	18.23	0.04	16.34
65	0.05	17.92		0.05	17.93	0.04	34.00	0.03		17.27	0.04	17.30	0.07	17.38	0.10	17.41	0.07	20.76	0.05	17.31
70	0.05	17.92		0.05	17.93	0.04	37.00	0.03		18.40	0.04	20.00	0.08	18.53	0.11	18.56	0.0798	23.945	0.055	18.45
75	0.05	17.92		0.05	17.93	0.05	39.84	0.03		19.71	0.04	21.40	0.09	19.57	0.13	19.94	0.08	25.67	0.06	19.75
80	0.05	17.91		0.05	17.92	0.05	42.94	0.03		21.21	0.05	23.44	0.09	22.54	0.14	24.77	0.097	26.78	0.07	22.54
85	0.05	17.91		0.05	17.92	0.05	43.96	0.03		21.21	0.06	24.44	0.99	23.97	0.15	26.97	0.10	27.76	0.08	24.98
90	0.05	17.91		0.05	17.92	0.05	45.94	0.04		24.77	0.06	25.44	0.10	25.90	0.17	27.92	0.13	28.34	0.09	25.67
95	0.05	17.91		0.05	17.92	0.05	49.95	0.04		26.85	0.06	27.44	0.11	27.09	0.189	28.42	0.15	29.01	0.10	27.98
100	0.05	17.90		0.05	17.92	0.06	58.36	0.04		29.13	0.06	29.19	0.119	29.33	0.19	29.42	0.16	29.38	0.10	29.27

X: Active power loss (in MW). Y: Reactive power loss (in Mvar).

The load buses were identified as bus no. 4, 5, 7, 9, 10, 11, 12, 13 and 14. The DG capacities from 1 MW to 100 MW were penetrated at each load bus after correctly and technically facilitating the system. The result revealed that the power losses were reduced until a specific value of DG capacity, and after that particular value of DG penetration, the loss was increased. This point of minimum failure was selected as the optimal

capacity of DG of that load bus. Simulation of the system in ETAP made a comparison of power losses at various lines under the presence of DG of varying capacity at different buses. The results were analyzed and are presented below in Figure 5 and Table VI. The load buses with appropriate DG capacity, which can create minimum system loss, are shown in Table VII. The most favorable buses for DG penetration are shown in Table VIII after validation

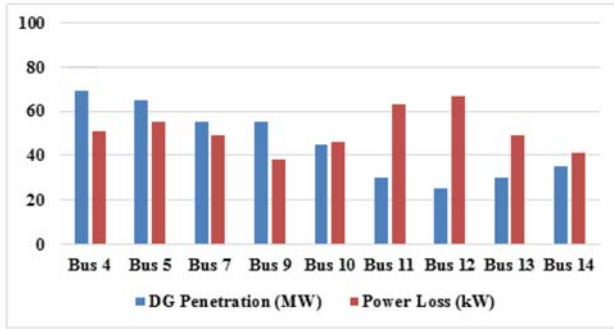


Fig.5 . Validation of the proposed algorithm with bar charts for various DGs at all load buses with respective system losses for the 14-bus system of IEEE.

TABLE VII THE LOAD BUSES WITH APPROPRIATE DG CAPACITY FOR MINIMUM POWER LOSS AT EACH LOAD BUS FOR THE 14-BUS SYSTEM OF IEEE

DG Bus	Penetrated DG Capacity in MW	Minimum Loss in System MW
Bus No. 4	70.0	0.0510
Bus No. 5	65.0	0.0550
Bus No. 7	55.0	0.0490
Bus No. 9	55.0	0.0380
Bus No. 10	45.0	0.0460
Bus No. 11	30.0	0.0630
Bus No. 12	25.0	0.0670
Bus No. 13	30.0	0.0490
Bus No. 14	35.0	0.0410

TABLE VIII OPTIMAL SIZES OF LOCAL GENERATORS OR DGs WITH BUS NUMBERS FOR THE 14-BUS SYSTEM OF IEEE

DG Bus	DG Size in MW
Bus No. 7	55.0
Bus No. 9	55.0
Bus No. 10	45.0
Bus No. 14	35.0

VII CASE STUDY FOR CONGESTION MANAGEMENT USING THE FORMULATED ALGORITHM IN THE PRACTICAL INTERCONNECTED GRID SYSTEM OF THE SUPPLY ENTITY OF THE STATE OF KERALA, KSEBL, INDIA

A single-line diagram of the part of the interconnected grid system of the supply entity of the state of Kerala, KSEBL, is shown in Figure 6. The system consisted of 54 numbers of various buses with voltage levels of 400 kV, 220 kV, 110 kV, 66 kV and 33 kV with 80 branches of transmission lines or connections and 14 generators generating 566.933 MW power delivering 17 loads of various specifications, out of which 543.32 MW was active power and 297.93 Mvar was reactive load, producing a loss of 22.613 MW in the system under normal running conditions without any obstruction of energy flows in the feeders. The practical system was implemented in ETAP®, an analysis of power flow solutions was conducted for the typical load profile and the percentage violation of the loading in each transmission line was obtained from the simulation. From the values of the thermal limit of each line and the apparent flowing power of the line in MVA, it was observed that none of the lines was overloaded, nor did the line have a severity index component of each branch (SICB) greater than one, and hence, there was no congestion in the system when there was no feeder interruption in the network. The effect of outage of a typical line of 400 kV, L91_4003 transmitting an apparent power of 240.9 MVA in the system was studied using the ETAP® simulation, and the results are given in Table IX for observing the status of the congested feeders L17_16 and L17_13 of the practical grid system. These feeders had SICB values of 3.50 and 2.04 with violation percentages of 87.51 and 42.77, respectively, showing concrete proof of the congestion in the system under the outage of L91_4003.

Repeated simulation studies were conducted using the ETAP® simulation for the outage of each transmission line to assess the congestion. The sensitivity factor (SF) determined the best sites/buses for integrating local generators or DGs into the system to solve congested feeders in the transmission network. The SF for each case of DG penetration of 5 MW at different buses was determined from the load flow results obtained by simulation using ETAP software. It was regarded that the negative values of SF reflected the suitability of that location for the placement of DGs or local generators for managing congested feeders in

the system. The analysis revealed that, for line outage L91_4003, buses 1, 2, 3, 4, 8, 10, 17, 110 and 125 were considered feasible buses for a congestion solution, as shown in Table X. The power loss at each line is a critical factor to be considered during the integration of DGs at buses for making the feeders free from power flow obstruction, and this approach was considered in this work to arrive at the best size of DG source for relieving the congested feeders on the occasion of interruption in the network. The capacity of DG size, which, when injected into the system, resulted in minimum power loss, could alleviate the congested feeders, and it was regarded as the best size for the integration of local generators or DGs, as shown in Table X. Thus, different scenarios for

congestion relief were obtained by power flow solutions of the system for the critical interruption event (interruption of line 91_4003). The conditions for feasible placing and quantifying DG allocations were determined and are presented in Table 10. The interruption of L91_4003 will create overloading only in the feeders of L16_17 and L17_13, and the loading of these feeders was observed by placing a DG capacity of 5 MW at each load bus. After the interruption of the feeder L91_4003, the MW loss in the practical grid system was observed as 21.644 MW without placing any DG. The events where the apparent flows in feeders

L16_17 and L17_13 were reduced during the interruption of L91_4003 than that of the flow during

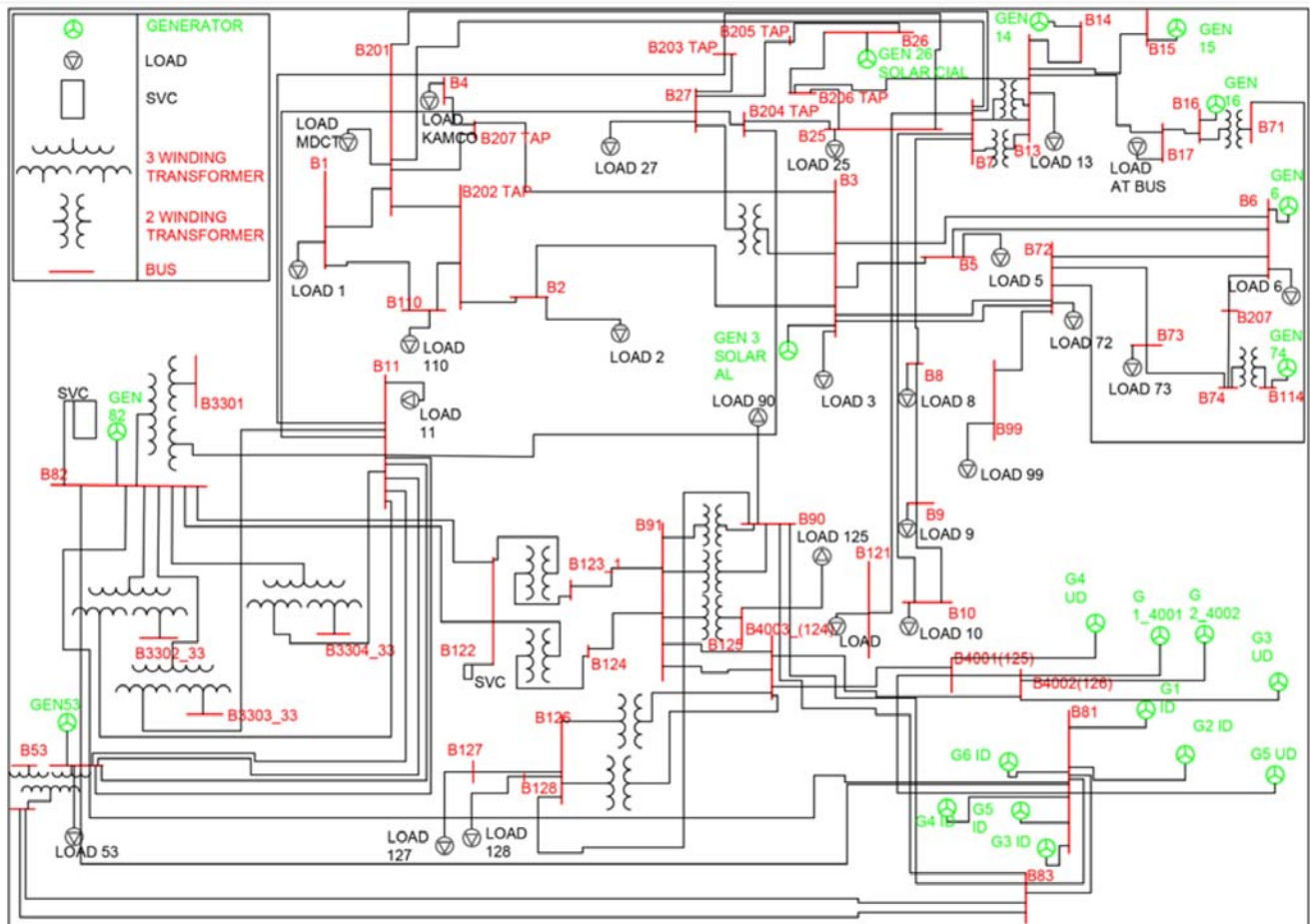


Fig 6 Single line diagram of the part of the interconnected transmission system of the supply entity of the state of Kerala, KSEBL.

the usual running case, showing that the SF values were least negative. Power flow solutions of the system with DG penetration revealed that the recognized buses 1, 2, 3, 4, 8, 10, 17, 110 and 125 were considered feasible buses for integration of DG as a remedial solution after the outage of line 91_4003, as these buses had negative values of SF while buses 25, 27, 53 and 72 had positive or zero values of SF, providing a proactive indication for not considering these buses for the best solution, as given in Table X. The load buses 1, 2 and 110 produced minimum losses of 19.58 MW with the allocation of DGs of capacities of 35 MW. Their SF values were investigated and found to be very low compared to other SF values in the group of buses 25, 27, 53 and 72, as given in Table 10. The load buses 3, 4, 8, 10 and 17 produced losses in the range of 20 MW whose SF values were also negative,

but more excellent or nearer to the SF values than the group of buses 1, 2 and 110. The buses 25, 27, 53 and 72 produced losses above 21 MW due to their zero or positive values of SF and, hence, these were not considered for comprehensive optima, as predicted in Table X. The 220 kV bus no.125 was regarded for DG allocation due to its high capacity of 100 MW with a minimum loss of 21.644 MW. The analysis revealed that integrating DG sources of appropriate capacity at buses whose SF values were least negative would help to find a solution for the congested feeders in the practical grid system, particularly when line 91_4003 is interrupted in the same system. The power loss at various lines for DG penetration of capacity which offered minimum power loss when injected at different buses was identified, and the optimal capacity of the DG and bus with minimum loss is shown in Table XI

TABLE IX VIOLATION %, SICBS AND APPARENT POWER FLOW IN THE BRANCHES OF THE PRACTICAL SYSTEM WITH AN OUTAGE OF L91_4003(1), RESULTING IN CONGESTION AT L16_17 AND L17_13 FEEDER (N-1 CONTINGENCY ANALYSIS).

L/T	Bus (from)	Bus (to)	MW	Mvar	Thermal Limit	MVA	Violation %	SICB	X	Y
L82_122	82	122	9.032	24.554	276.635	26.16249	-90.56	<1	17.29	84.36
L7_10	7	10	10.638	6.558	29.035	12.49698	-56.95	<1	272.7	212.1
L11_53	11	53	0.212	-1.637	65.348	1.65067	-97.47	<1	1.48	1.17
L72_3	72	3	13.974	2.405	65.348	14.17945	-78.30	<1	257.5	348.4
L82_81	82	81	42.567	50.625	276.635	66.14257	-76.09	<1	239.5	1301.6
L81_83	81	83	0	0	276.635	0	-100	<1	0	0
L85_83	85	83	9.322	9.231	276.635	13.11	-95.25	<1	24.76	133.8
L1_110	1	110	14.405	4.708	65.348	15.15	-76.80	<1	31.1	42.26
L1_201T	1	201tap	28.681	13.565	29.035	31.72	9.27	<1	13.02	17.6
L7_201T	7	201tap	25.715	13.884	29.035	29.22	0.65	<1	664.7	898.4
L2_3	2	3	11.864	-2.996	29.035	12.23	-57.85	<1	65.07	88.5
L11_53	11	53	0.212	-1.637	65.348	1.65	-97.47	<1	1.48	1.17
L72_3	72	3	13.974	2.405	29.035	14.17	-51.16	<1	257.5	348.4
81_82	81	82	68.505	81.473	276.635	106.44	-61.521	<1	385.5	2094.7
L81_83	81	83	0	0	276.635	0	-100	<1	0	0
L7_201T	7	201tap	25.715	13.884	29.035	29.22	0.65	<1	664.7	898.4

L3_5	3	5	3.461	-15.506	29.035	15.88	-45.28	<1	39.49	58.79
L3_6	3	6	8.577	-2.877	29.035	9.04	-68.84	<1	543.2	735.2
L11_53(1)	11	53	0.212	-1.637	65.348	1.65	-97.47	<1	1.48	1.17
L11"53(2)	11	53	0.212	-1.637	65.348	1.65	-97.47	<1	1.48	1.17
L6_5	6	5	18.089	-5.62	29.035	18.94	-34.76	<1	1131.6	1487.5
L6_207T	6	207tap	10.664	-14.974	29.035	18.38	-36.68	<1	170	229.9
L7_8	7	8	23.515	14.735	29.035	27.75	-4.42	<1	473	373.4
L8_9	8	9	3.153	2.035	29.035	3.75	-87.07	<1	8.09	6.28
L9_10	9	10	3.145	2.029	29.035	3.742	-87.10	<1	9.51	8.09
L11_203T	11	203tap	43.495	40.486	65.348	59.42	-9.06	<1	332.8	520.1
L11_204T	11	204tap	47.948	40.845	65.348	62.98	-3.61	<1	374.4	512.8
L13_206	13	206tap	30.691	32.664	65.348	44.82	-31.41	<1	784.9	1225
L16_17	16	17	103.708	65.264	65.348	122.53	87.51	3.50	4355.5	6800.1
L17_13	17	13	80.667	46.884	65.348	93.30	42.77	2.04	2526	3942.5
L25_204T	25	204tap	17.655	14.675	65.348	22.95	-64.86	<1	163.4	255
L25_205T	26	205tap	17.881	17.367	65.348	24.92	-61.85	<1	198.4	309.9
L26_206T	26	206tap	17.683	17.057	65.348	24.56	-62.40	<1	21.8	34.09
L25_27	25	27	17.905	17.405	65.348	24.97	-61.78	<1	24.14	37.67
L13_201T	13	201tap	7.939	4.943	29.035	9.357	-67.79	<1	22.63	36.75
L207T_201T	207tap	201tap	3.99	4.68	29.035	6.15	-78.81	<1	29.65	48.15
L3_207T	3	207tap	19.882	10.286	29.035	22.38	-22.90	<1	108	175.9
L4_207	4	207tap	23.734	14.741	29.035	27.93	-3.77	<1	32.22	52.33
L82_122(2)	82	122	9.032	24.554	276.635	26.16	-90.54	<1	17.29	84.36
L83_85(2)	83	85	15.003	14.856	276.635	21.11	-92.36	<1	39.85	215.4
L123_91	123	91	18.004	47.634	276.635	50.929	-81.59	<1	44.21	424.1
L71_72	71	72	20.903	18.137	276.635	27.67	-89.99	<1	680.6	915.2
L72_73	72	73	15.256	-7.479	29.035	16.99	-41.48	<1	354.2	484.7
L73_74	73	74	15.508	-7.137	29.035	17.071	-41.20	<1	251.6	341.9
L91_4003(2)	91	4003	197.75	403.395	609.68	449.25	-26.31	<1	1764.6	16,390.9
L90_83(1)	90	83	24.995	-35.672	276.635	43.55	-84.25	<1	312.2	1522.9
L90_83(2)	90	83	24.995	-35.672	276.635	43.55	-84.25	<1	312.2	1522.9
L4003_4001	4003	4001	105.721	182.002	609.68	210.47	-65.47	<1	415.3	4053.6
L27_203T	27	203tap	24.99	24.479	65.348	34.98	-46.46	<1	47.07	73.58
L4003_4002	4003	4002	105.721	182.002	609.68	210.47	-65.47	<1	415.3	4053.6
L126_90	126	90	12.499	-49.787	276.635	51.33	-81.44	<1	350.8	1711.4
L127_126	127	126	0	0	276.635	0	-100	<1	0	0
L128_126	128	126	0	0	276.635	0	-100	<1	0	0
L110_202T	120	110	0.121	-4.168	65.348	4.16	-93.61	<1	0.528	0.713
L201T_202T	201tap	202tap	9.49	2.784	65.348	9.88	-84.86	<1	24.04	32.5
L2_202T	202tap	2	9.587	-1.416	65.348	9.69	-85.17	<1	16.07	21.97

L25_203	203tap	25	18.172	15.486	65.348	23.87	-63.46	<1	165.8	258.8
L27_204T	27	204tap	29.918	25.657	65.348	39.41	-39.68	<1	59.72	93.35
L25_206T	25	206tap	13.117	15.777	65.348	20.51	-68.60	<1	87.41	136.5
L74_207	74	207	10.63	-15.02	29.035	18.40	-36.62	<1	34.29	46.36
T	85	T	24.26	23.738	160	33.94	-78.78	<1	29.4	1646.3
T	53	T	24.231	22.092	160	32.79	-79.50	<1	29.4	1646.3
T	TER11	T	0	0	160	0	-100	<1	29.4	1646.3
T	91	T	8.198	169.843	315	170.04	-46.01	<1	253.4	12,671.3
T	91	T	17.205	446.129	315	446.46	41.73	<1	2039	101,949
T	91	T	188.289	145.257	315	237.80	-24.50	<1	578.5	28,924.6
T	4003	T	6.425	-24.038	315	24.88	-92.10	<1	5.77	288.7
T	4003	T	6.425	-24.038	315	24.88	-92.10	<1	5.77	288.7
T	124	T	0	0	315	0	-100	<1	0	0
T	82	T	25.662	22.109	200	33.87	-83.068	<1	23.85	1335.3
T	11	T	25.638	20.774	200	32.99	-83.50	<1	23.85	1335.3
T	3301	T	0	0	200	0	-100	<1	23.85	1335.3
T	123	T	18.03	48.939	315	52.15	-83.44	<1	26.1	1304.9
T	82	T	25.662	22.109	200	33.87	-83.06	<1	23.85	1335.3
T	11	T	25.638	20.774	200	32.99	-83.50	<1	23.85	1335.3
T	3302	T	0	0	200	0	-100	<1	23.85	1335.3
T	82	T	25.662	22.109	200	33.87	-83.06	<1	23.85	1335.3
T	11	T	25.638	20.774	200	32.99	-83.50	<1	23.85	1335.3
T	3303	T	0	0	200	0	-100	<1	23.85	1335.3
T	82	T	15.397	13.266	120	20.32	-83.06	<1	14.31	801.2
T	11	T	15.383	12.464	120	19.79	-83.50	<1	14.31	801.2
T	3304	T	0	0	120	0	-100	<1	14.31	801.2
T	13	T,7	42.989	30.351	60	52.62	-12.29	<1	197.3	5821
T	13	T,7	42.989	30.351	60	52.62	-12.29	<1	197.3	5821
T	13	T,27	14.434	18.644	60	23.57	-60.70	<1	225.3	4190.5
T	71	T,16	21.214	23.921	60	31.97	-46.71	<1	311	5784.4
T	114	T,74	5.038	9.829	20	11.04	-44.77	<1	160.2	1945.2

TABLE X FEASIBLE BUSES IN THE PRACTICAL GRID SYSTEM FOR SELECTING OPTIMAL BUSES FOR DG PENETRATION THROUGH THE DEVELOPED ALGORITHM DURING THE OUTAGE OF L91-4003

DG Bus	SF L16_17	SF L17_13	4	-0.201	-0.190
			8	-0.314	-0.290
17	-0.3928	-0.168	10	-0.314	-0.290
1	-0.278	-0.258	25	0.000	0.000
2	-0.256	-0.238	27	0.000	0.000
3	-0.214	-0.200	53	+0.0052	0.000

72	0.000	0.000
125	-0.0002	-0.0002
110	-0.4068	-0.380

Table XI. Congestion solution tabulation through the formulated algorithm for the practical grid system with the allocation of DGs.

DG Bus	Penetrated DG Capacity in MW	Minimum System Loss in MW
Bus No. 110	35.0	19.581
Bus No. 1	35.0	19.595
Bus No. 10	20.0	21.717
Bus No. 53	55.0	21.997
Bus No. 25	35.0	21.988
Bus No. 27	35.0	21.854
Bus No. 17	35.0	21.145
Bus No. 2	35.0	19.580
Bus No. 3	30.0	20.130
Bus No. 8	35.0	20.458
Bus No. 72	35.0	22.041
Bus No. 125	100.0	21.644

VIII CONCLUSION

The development of a load flow-based approach to determine the optimum size and size penetration of DGs for the release of congested feeders from overloading in a transmission system was presented in this paper. The IEEE 14-bus system was considered in the study with rescheduled generation to introduce various line outage cases and analyze the effect of DG penetration on congestion management by power flow solutions. The analysis of the power flow solutions on all transmission lines in the system for various outage cases was carried out, and the combined use of two parameters, such as severity index (SI) and percentage violation, proved its reliability to assess the extent of power flow obstruction of feeders due to feeder outages. The method revealed the most critical case as an outage of transmission line L6_13 in the 14-bus system of IEEE and was considered in the paper for further analysis to develop a method for the most favorable placement and quantification of DGs for congestion management. The

use of an index parameter, the sensitivity factor (SF), defined as the ratio of change in apparent power flow along a line concerning the change in penetrated DG capacity at the bus, demonstrated its reliability in identifying the achievable buses for DG penetration to attain a congestion-free environment in feeders. The power loss at each line during each case of DG allocation at workable buses was made to identify the most favourable location and size of DG to reduce obstruction of power flow along feeders. The distributed generation or local generator, which yielded to relieve the environment of overloading in all the feeders with minimum power loss in the system during the outage condition, was regarded as the most favourable case of DG allocation for congestion management. The power flow solutions on the network with feeder outage of L6_13 in the 14-bus system of IEEE with various sizes and locations for DG penetration revealed the adoption of appropriate capacity and a most favourable bus as the most optimum size and location for DG penetration to relieve the congested feeders in the transmission network. The reliability of the formulated approach was examined on the transmission network with various capacities of DGs at all buses in the IEEE bus system, which still yielded the obtained feasible solution as the optimum DG penetration case for congestion management. The investigated scheme for the best placement and quantification of local generators or DGs was verified by the power flow solution of the network with DGs of different sizes at all the buses in the system, and the reliability of the sensitivity factor was revealed. The system indices SI and DGSF provided a proactive indication to predict the potential bus locations for the finest solution of DG penetration in the system. Where appropriate DGSF values are obtained, only those buses should be tested to find the finest buses. As the proposed technique was based on mathematical methods, no approximations were linked with this algorithm. Comprehensive bests arrive while obtaining the solution for optimal bus and DG capacity to integrate the system with DGs. The simulation results were speedy, and appropriate convergence was received in the solution without any divergence probability through this algorithm. The practical application of the proposed algorithm was successfully tested in the grid system of the supply entity of the state of Kerala, comprising a large number of buses, and the best location and size

for the allocation of DGs for congestion solution in the most critical case was determined by the presented algorithm. This method proposed a less complex algorithm for the most efficient detection of the best placing and quantifying of DG in a system of interconnected transmission networks.

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SAFETY CLEARANCE TRANSMISSION						
Voltage	Clearance to Ground		Elsewhere		Clearance from Building	
	Across the street	Along the street	Bare	Insulated	Vertical clearance from the highest roof	Horizontal clearance from the nearest point
	m	m	m	m	m	m
Up to 650 v	5.8	5.5	4.6	4	2.5	1.2
up to 11 KV	6.1	5.8	4.6	4	2.5	1.2
11 - 33 KV	6.1	5.8	5.2	-	3.7	2
66 KV*	6.1	6.1	6.1	-	4.0	2.3
110 KV*	6.402	6.402	6.402	-	4.6	2.9
220 KV*	7.012	7.012	7.012	-	5.5	3.8
400 KV*	9.76	9.45	8.85	-	7.3	5.6
*For EHV lines, the clearance above the ground shall not be less than 5.2 metres plus 0.3 metres for every 33 KV or part there of by which the voltage of the line exceeds 33 KV. The minimum clearance along or across any street shall not be less than 6.1 metres.						

Arc Furnaces: Implications on Power Systems and Six Phase Furnace Transformers

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In the intricate realm of metallurgy and steelmaking, the arc furnace stands as a symbol of innovation, efficiency, and adaptability. This pivotal piece of equipment has revolutionized the way metals are melted, refined, and transformed into usable materials. This article delves into the fundamental function and working principles of an arc furnace, shedding light on the captivating process that underlies modern steel production.

Function of an Arc Furnace: At its core, an arc furnace serves as a vessel for melting various types of metals and alloys, most notably steel. Its primary function is to generate an intensely hot environment through the utilization of an electric arc, a

controlled discharge of electricity between two electrodes. The heat generated by this arc is what induces the transformation of solid metal materials into a molten state, allowing for further refinement and manipulation.

Working Principles: The working of an arc furnace is an orchestrated dance of electrical, thermal, and chemical phenomena. Let's break down the process step by step:

Charging: The furnace is charged with raw materials, which typically include scrap metal, alloys, and additives. These materials serve as the feedstock for the steel production process.

Electrodes: Two electrodes, usually made of graphite, are positioned vertically or at an angle inside the furnace. These electrodes are the conduits through which electrical energy is supplied to the furnace.

Arc Initiation: When the electrodes are brought close to each other, a high-voltage electrical potential difference is applied between them. This potential difference ionizes the air, creating a conductive path and initiating an electric arc between the electrodes.

Heat Generation: As the electric arc forms, an incredible amount of heat is generated—reaching temperatures that can exceed 3,000 degrees Celsius. This extreme heat causes the solid raw materials in the furnace to gradually melt and transition into liquid form.

Melting and Refining: The heat generated by the arc not only melts the metal scrap but also facilitates chemical reactions that aid in refining the metal. Impurities in the scrap material are oxidized or reduced, leading to the removal of unwanted elements and the enhancement of the metal's quality.

Additives and Alloying: During the melting process, various alloying elements and additives can be introduced to achieve specific material properties. These additions are carefully calculated to ensure the final product meets the desired specifications.

Temperature Control: Achieving the right temperature and maintaining it consistently are essential for producing quality steel. The operator can adjust the arc length, current intensity, and electrode positioning to control the heat output and temperature.

Tap-Out: Once the desired level of melting and refining has been achieved, the furnace is tapped. This involves tilting the furnace to pour the molten metal into ladles or molds for further processing.

Slag Formation: In addition to the metal, a layer of slag is also formed during the melting process. This slag consists of impurities that have been separated from the metal. It floats on top of the molten metal and is removed before tapping.

Innovations and Variations : Arc furnaces come in various designs, each catering to specific production requirements. For instance, some arc furnaces use direct current (DC) while others use alternating current (AC) for powering the electrodes and generating the arc. Additionally, advancements in automation, process

control, and environmental considerations have led to the development of more efficient and eco-friendly arc furnace technologies.

Arc Furnace Harmonics in Steel Plants: Causes, Effects, and Mitigation Strategies : In the realm of modern steel production, arc furnaces have emerged as essential tools, facilitating the transformation of raw materials into molten metal through intense electrical arcs. While these furnaces offer efficiency and flexibility, they also introduce a complex challenge known as harmonics. Harmonics are the result of nonlinear loads, like arc furnaces, injecting distorted currents into the power system, which can lead to a range of adverse effects. The causes, effects, and mitigation strategies associated with harmonics due to arc furnaces in steel plants are discussed below.

Causes of Harmonics: Arc furnaces operate by maintaining an electric arc between the electrodes and the charged metal. This process involves rapidly changing voltage and current levels, leading to a nonlinear behaviour that generates harmonics. Unlike linear loads, which draw sinusoidal currents, arc furnaces draw current in abrupt, jagged pulses. These pulses contain higher-frequency components that are multiples of the fundamental frequency (usually 50 or 60 Hz), creating harmonics. The rapid switching of power semiconductors in the furnace's control circuitry further exacerbates the generation of harmonics.

Effects of Harmonics: The injection of harmonics into the power system can have far-reaching consequences. Voltage distortion is a common problem, leading to distorted sinusoidal waveforms. This distortion can affect sensitive equipment, cause overheating in transformers and cables due to increased losses, and reduce the lifespan of electrical components. Furthermore, harmonics can induce resonance in the system, amplifying voltage levels at specific frequencies and potentially causing equipment damage. In steel plants, where precise control is crucial, harmonics can disrupt the accuracy of control systems, impacting the quality of the steel produced.

Mitigation Strategies

Mitigating harmonics requires a multifaceted approach that involves both design considerations and active measures. Some effective strategies include:

1. Harmonic Filters: These are specialized devices

that provide a low-impedance path to the harmonic frequencies, diverting them away from the main electrical system. They consist of capacitors, inductors, and resistors tuned to specific harmonic frequencies. By absorbing or cancelling out harmonics, these filters help maintain the quality of power within acceptable limits.

- 2. Power Factor Correction:** Improving the power factor of the system reduces the apparent power drawn from the grid, thereby decreasing the load on the system caused by harmonics. Capacitor banks are often employed to offset the reactive power and improve power factor, reducing the impact of harmonics.
- 3. Isolation Transformers:** These transformers decouple the arc furnace from the rest of the electrical system. By providing electrical isolation, they prevent the propagation of harmonics to other parts of the network.
- 4. Harmonic-Reducing Equipment:** Using modern power electronics, such as active harmonic filters and line reactors, can effectively suppress harmonic currents generated by arc furnaces.
- 5. System Design:** Proper system design involves segregating harmonic-producing loads from sensitive equipment. This minimizes the potential for interference and reduces the need for extensive harmonic mitigation measures.
- 6. Advanced Control Strategies:** Implementing advanced control algorithms that regulate the firing angles of power electronic devices in arc furnaces can help minimize harmonic generation. While arc furnaces play a pivotal role in steel production, their nonlinear nature introduces the challenge of harmonics in power systems. The resulting effects, including voltage distortion and equipment malfunction, necessitate diligent mitigation efforts. Steel plants must adopt a comprehensive approach that combines harmonic filters, power factor correction, isolation transformers, advanced control techniques, and thoughtful system design. By doing so, the steel industry can harness the benefits of arc furnaces while maintaining the reliability and efficiency of their power systems.

Enhancing Steel Production Efficiency: The Role of Six-Phase Transformers in Arc Furnaces :

In the dynamic landscape of steel production, innovation continues to reshape traditional processes. One such innovation is the utilization of six-phase transformers in arc furnaces within steel plants. These specialized transformers offer a range of advantages that contribute to increased efficiency, improved power quality, and enhanced control over the steelmaking process. We shall discuss the significance of six-phase transformers and their role in optimizing arc furnace operations

Evolution from Three-Phase to Six-Phase

Traditionally, three-phase transformers have been the backbone of power distribution systems. However, the demands of arc furnace operation, characterized by intense and nonlinear power consumption, necessitated a more advanced solution. This led to the development and implementation of six-phase transformers. Unlike their three-phase counterparts, which have three primary and three secondary windings, six-phase transformers incorporate six primary and six secondary windings. This configuration allows for greater flexibility in power distribution and enhanced harmonic mitigation.

Advantages of Six-Phase Transformers

1. **Improved Power Quality:** Arc furnaces are notorious for generating harmonics due to their nonlinear operation. Six-phase transformers are better equipped to handle these harmonics, as the additional phases allow for more precise control over current flow. This results in reduced harmonic distortion, leading to better power quality and decreased stress on the electrical system.
2. **Enhanced Efficiency:** Six-phase transformers facilitate more balanced current distribution among the phases, reducing the risk of overloading individual phases. This improved current sharing not only enhances the efficiency of the transformer itself but also minimizes losses in associated equipment such as cables, switches, and circuit breakers.
3. **Optimized Utilization of Power**

Sources: Steel plants often rely on multiple power sources to meet the energy demands of arc furnaces. Six-phase transformers enable efficient utilization of these sources by distributing power evenly across all phases. This ensures that power

sources are utilized to their maximum capacity, reducing the need for costly upgrades and improving overall energy efficiency.

4. **Reduced Voltage Drop:** The enhanced current distribution achieved through six-phase transformers helps mitigate voltage drops, which can be particularly critical in large steel plants with extensive power distribution networks. This reduction in voltage drop ensures consistent and stable voltage supply to critical equipment, preventing disruptions in the steel-making process.
5. **Enhanced Control and Flexibility:** Six-phase transformers provide greater control over the distribution of power to various parts of the steel plant. This increased flexibility allows for better adaptation to varying load conditions and production requirements, ultimately leading to improved process control and product quality.

Challenges and Considerations: While the benefits of six-phase transformers are substantial, their adoption does come with certain challenges and considerations. Implementing these transformers may require modifications to the existing power distribution infrastructure. Additionally, specialized expertise is needed for the design, installation, and maintenance of six-phase systems. However, the long-term advantages in terms of efficiency, power quality, and process control often outweigh these initial challenges. In the pursuit of operational excellence, steel plants are embracing innovative technologies that optimize existing processes. Six-phase transformers stand out as a prime example of such innovation. By addressing the unique challenges posed by arc furnace operations, these transformers elevate power distribution systems to new heights of efficiency and reliability. The advantages of improved power quality, enhanced efficiency, optimized power source utilization, and enhanced control position six-phase transformers as a critical component in the evolution of steel production. As the steel industry continues to evolve, the integration of six-phase transformers into arc furnace operations is poised to play a pivotal role in shaping a more sustainable and efficient future.

You would generally find the following components and connections in 6 winding transformers.

- 1. Primary Windings:** Six-phase transformers have six primary windings, which are connected to the power sources. These windings are designed to handle the high current demands of the arc furnace operation.
 - 2. Secondary Windings:** Similarly, there are six secondary windings connected to the load (arc furnace). The secondary windings provide the necessary voltage and current for the arc furnace process.
 - 3. Phase Shifting:** Six-phase transformers are often used in conjunction with phase-shifting devices or arrangements to adjust the phase relationships between the primary and secondary windings. This allows for precise control over the power delivery to the furnace.
 - 4. Harmonic Filters:** To mitigate harmonics generated by the non-linear load of the arc furnace, harmonic filters can be included in the block diagram. These filters help maintain the quality of power and reduce disturbances in the electrical system.
 - 5. Cooling System:** Transformers generate heat during operation, and in an arc furnace environment, the heat generation can be substantial. A cooling system, which could involve fans or oil cooling, is typically incorporated to keep the transformer operating within safe temperature limits.
- Remember, the arrangement and specifics of the block diagram can vary based on the manufacturer, design, and intended application of the 6-phase transformer for the arc furnace.
- For an example let us discuss about a 6750KVA transformer. Here two transformer of capacity 3375KVA each may be placed in same transformer tank having two independent cores.

Two Transformers (3375KVA, with Total 6750 KVA) shall be placed in ONE TANK having two independent

cores. Common H. V. connections should be brought out & four secondary terminals separately brought out.

	TRANSFORMER - 1	TRANSFORMER - 2
Continuous Rating	3375 KVA	3375KVA.
Primary Winding		
No of Phases	3	3
Frequency	50 Hz.	50 Hz.

Interphase	Extended Delta (+7.5°)	Extended Delta (-7.5°)	s		
Connection Secondary Winding			Interphase Connection		
Terminal Voltage at 0.95 P.F. at F.L.	575 Volts	575Volts.	Secondary I	Delta	Delta
No of Phase	6	6	Secondary II	Star	Star
			Current per Phase	Full load Rated Current 1694 Amps. Max. current at -10% of rated Voltage = 1882 Amps	Full load Rated Current = 1694 Amps. Max. current at -10% of rated Voltage = 1882 Amps

current rating	Transformer should be capable to deliver rated kVA on -10% rated voltage also hence current rating should be 10% more	Transformer should be capable to deliver rated kVA on -10% rated voltage should be 10%
	Vector Group	ED(+7.5°) doy11 ED(-7.5°) doy11

Let us discuss with another example for arc furnace transformer

Furnace Transformer 7200 KVA, 33 KV / 570 V x4

Sl No	Description	Unit
1	Rated Power	KVA
2	Rated voltage	
	HV Winding	KV
	LV Winding 1	KV
	LV Winding 2	KV
	LV Winding 3	KV
	LV Winding 4	KV
3	Voltage ratio	
4	Frequency	Hz
5	Cooling	

6	Rated Power	
	HV Winding	KVA
	LV Winding 1	KVA
	LV Winding 2	KVA
	LV Winding 3	KVA
	LV Winding 4	KVA
7	Rated Current	
	HV Winding	A
	LV Winding 1	A
	LV Winding 2	A
	LV Winding 3	A
	LV Winding 4	A 1823.2
8	Winding Connection	
	HV Winding Delta	
	LV Winding 1	Star
	LV Winding 2	Delta
	LV Winding 3	Ext. Delta
	LV Winding 4	Red Delta
	Vector Group	Extended Delta

Extended Delta windings, also known as Zigzag windings, are a specialized configuration used in transformers to provide certain advantages in terms of fault tolerance and grounding capabilities. In a traditional Delta winding, the three phases are connected in a triangular fashion, but in extended Delta windings, an extra set of windings or “zigzag” windings are added.

One primary advantage of extended Delta windings is their fault tolerance. If a fault occurs on one of the phases, the zigzag winding allows the transformer to continue operation, albeit with reduced capacity, until repairs can be made. This is a significant benefit in critical applications where downtime must be minimized.

Another important feature of extended Delta windings is their grounding capability. These windings provide a path for zero-sequence currents, which are essential for fault detection and protection schemes. By

effectively grounding the system, extended Delta windings enhance safety and reduce the risk of electrical fires and damage to equipment.

Extended Delta windings are also employed in applications where harmonic currents are a concern. They can help mitigate harmonics, which can be detrimental to both the transformer and the connected electrical system.

Despite these advantages, extended Delta windings are not without drawbacks. They are more complex and costly to manufacture than standard Delta windings, and their operation can be less efficient due to additional copper losses.

Reduced Delta secondary windings, often referred to as “Reduced Delta” or “Reduced Voltage Delta” connections, are a specialized configuration employed in power transformers to mitigate certain voltage issues and enhance system performance. This configuration is particularly valuable in steel industry settings where voltage control is crucial.

In a Reduced Delta secondary winding, only a portion of the winding is connected in a delta configuration, while the remaining part is connected in a Wye (star) configuration. This essentially reduces the secondary voltage compared to a full delta winding.

The primary advantage of Reduced Delta secondary windings is voltage control. By lowering the secondary voltage compared to a full delta winding, they allow for better regulation of voltage levels in the system. This is especially beneficial when dealing with loads that are sensitive to voltage fluctuations. Reduced Delta configurations can help maintain a more stable voltage supply to critical equipment.

Additionally, Reduced Delta secondary windings can reduce the stresses on the insulation and winding materials, potentially extending the transformer’s lifespan. They can also help minimize voltage distortion and harmonics in the electrical system, leading to improved power quality.

However, it’s important to note that Reduced Delta connections come with some trade-offs. They may lead to increased transformer impedance and reduced power capacity compared to a full delta winding.

In arc furnace power transformers these are a valuable tool for voltage control and improving power

quality in industrial and commercial applications. They provide the benefits of voltage stability and reduced stress on the transformer.

The vector group Dyn11D0d(+15)d(-15) in a power transformer is a notation used to describe the winding connections and phase relationships of the transformer windings. Let’s break down what each component of this vector group represents:

1. “Dyn11”: This part of the vector group indicates the primary and secondary winding connections. “Dyn” stands for “Delta on the primary side” and “Y” on the secondary side, which means the primary winding is connected in a delta configuration, while the secondary winding is connected in a wye (star) configuration.

2. “D0d”: These letters represent the phase displacement between the primary and secondary windings. “D” signifies a 30-degree phase shift, and “0d” means no phase shift. So, there is a 30-degree phase shift from the primary to the secondary, and no phase shift within the secondary winding itself.

3. “(+15)d(-15)”: These values denote additional phase shifts within the secondary winding. “(+15)” indicates a positive 15-degree phase shift in one section of the secondary winding, and “(-15)” indicates a negative 15-degree phase shift in another section of the secondary winding. These phase shifts can be used to control the voltage characteristics of the transformer. The transformers can be equipped with an additioning star-delta switch (by this way a wide range for the secondary voltage is obtained).

Booster transformer

Such solution can also be used with medium and large furnace applications. The booster transformer increases the output of the fixed secondary voltage of the main transformer. The tap changer is installed on the tertiary winding. The voltage and current values of the tertiary are selected by the transformer manufacturer: such way offers an optimization of tapping operating condition. The manufacturer with such configuration has the advantage that can select the most idoneus tap changer.

Hence in Steel industry with arc furnace, quality of power and the adverse role it play in power system has to be given at most importance. All measures need to be taken care of to suppress harmonics. With the advance technology, new arc furnace transformers are been introduced to the power sector so as the disturbance of power quality on to the grid can be minimised.

Condition Monitoring of High Voltage Insulators

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Introduction

The electrical energy demand in India is expected to cross 9,50,000 MW by 2030, and the demand has grown at an average of 3.6 % over the past thirty years. While generating electrical energy poses a minimum of problems, transmission and distribution losses in India have been consistently on the high side. To minimize the losses, electrical energy is transmitted in bulk at higher voltages over thousands of kilometers. Most electrical energy is transmitted from power generating stations to distribution stations by overhead line (OHL) conductors. Overhead line conductors are supported at the transmission tower through insulators. The primary function of insulators is to isolate the transmission tower and the live conductor and to provide necessary mechanical support for the conductor.

The outdoor insulators used in transmission lines are either ceramic or non-ceramic (polymeric) insulators. Polymeric insulators are hydrophobic in nature and are increasingly used to replace traditional ceramic insulators. The major concern in developing polymeric insulators is the deterioration of the material since it is more prone to chemical changes due to its weak chemical bonding. Deterioration mainly occurs due to the combined effect of environmental stresses and electric stress. The hydrophobicity of the material will also be temporarily or permanently lost under these stresses. Such adverse effects can cause the insulator to fail to result in power outages. Hence, condition monitoring of high voltage insulators under the influence of contaminants is an essential task.

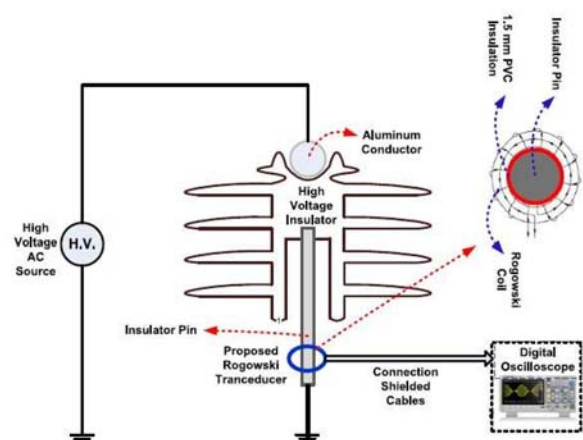
Objectives

- To measure the leakage current of the polymeric insulator under clean and contaminated conditions.
- To predict the degree of aging of the insulator due to contaminants and prevent power outages due to unprecedented flashovers.

Methodology

The proposed work concerns the condition monitoring of high voltage insulators under the influence of contaminants using a Rogowski coil surrounding the ground electrode of the high voltage insulator. The insulator can be sprayed with a saline solution according to IEC 60815 to simulate different pollution levels. The condition monitoring depends on the voltage signal that is generated in the Rogowski coil winding due to 1) capacitive coupling between the insulator and the coil and 2) a superimposed voltage signal generated in the coil winding due to electromagnetic induction that occurs due to leakage current over the insulator surface during contaminated conditions. The output voltage signal from coil winding (i.e. due to capacitive coupling and electromagnetic induction) can be analyzed using Fast Fourier Transform (FFT). The direct analysis of the output voltage signal from the Rogowski coil without the need for current reconstruction reduces the complexity of signal processing.

Block Diagram



Theory

A Rogowski coil is to be fitted around the ground electrode of the high voltage insulator. A thin polymeric layer will be fitted between the insulator electrode and the coil to prevent direct contact of coil winding with the electrode. When the insulator is dry/clean, a negligible leakage current will pass over the insulator surface. A voltage signal is generated in the Rogowski coil winding due to the capacitive coupling between the insulator pin and the coil winding. This voltage signal is expected to be a sinusoidal waveform with negligible distortion.

When the insulator is wet/polluted, leakage current in the order of milli Amperes will pass over the insulator surface. This current will result in the formation of dry bands due to water vaporization from regions of lower wetness. Therefore, dry band arcing is formed at the dry bands due to higher electric field intensity at these regions. So, leakage current rises immediately when dry band arcing is formed. It is to be noted that, the increase in pollution level will result in the formation of more dry band arcing. The flow of leakage current with dry band arcing over the insulator surface causes the formation of a magnetic field around the ground electrode. This magnetic field interacts with Rogowski coil winding, and an emf is generated through the coil. Hence, two voltage components are generated in the coil when the insulator surface is wet/polluted. The obtained voltage signal shall be compared and analyzed to get information on the condition of the high voltage insulators.

Outcomes

- A low-cost, simple tool to measure leakage current can be designed and implemented.

- Real-time online monitoring of polymeric insulators can be established.
- Unprecedented failure of insulators can be minimized.

Financial Implications

As per the latest statistics a 220kV line gets interrupted for approximately 600 hours in Kerala a year. That means the power loss of 100 MW equals to the loss of 60 MU in a year. Majority of interruptions in 220kV system is because of the insulator failure and the installation of online monitoring devices would reduce the outage duration to 300 hours, i.e. saving of 30 MU in a year which translates into 18 Cr profit (in a year) if Rs.6.00 is assumed per unit. By installing the proposed work, say at 1000 locations for condition monitoring, the overall expenditure is estimated to 6 Cr only.

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CODE OF PRACTICE – LEAD IDENTIFICATION (CONTROL WIRING - PROTECTION & METERING CIRCUITS)			
A series	C.T secondaries for special protection; A1, A2, A3 etc. (Distance /Differential / REF Protection)	H series	LT AC supply; H1, H2, H3 etc
B series	C.T secondary for Bus bar protection; B1, B2, B3 etc.	J series	Main DC incoming; J1 (+ve) J2 (-ve) etc.
C series	C.T Secondary for protection circuits; C1, C2, C3 etc. (Back up Protection Over Current & Earth Fault)	K series	Controls, closing, tripping; K1, K2, K3 etc.
D series	C.T secondaries for metering circuits; D1, D2, D3 etc.	L series	Alarm indication and annunciation; L1, L2, L3 etc
E series	Potential Transformer secondaries; E1, E2, E3 etc. (For protection and metering)	P series	DC Supply for Bus Bar Protection and LBB protection Circuit.

Trends in Lithium-Ion Battery Technology and Perspectives for the Future

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Among the various rechargeable battery technologies accessible today, lithium-ion batteries stand out as the premier electrochemical energy storage solution. Their acclaim is rooted in an impressive gravimetric energy density of approximately 260 watt-hours per kilogram, with the potential for further expansion to exceed 500 watt-hours per kilogram. Since their commercial introduction by SONY in 1991, lithium-ion batteries have found widespread application in the realm of portable electronic devices. Notably, Lithium-ion batteries are spearheading the transformation of transportation modes, shifting away from conventional, non-renewable fossil fuel-based internal combustion engines and toward the promising realm of electromobility. For instance, a conventional internal combustion engine consumes approximately 5.5 liters of gasoline to cover a distance of 100 kilometres, equivalent to around 50 kilowatt-hours of energy. In contrast, a lithium-ion battery powered electric vehicle can travel approximately 312 kilometers on the same amount of energy, translating to a mere 16 kilowatt-hours of energy consumption for the same 100-kilometer journey. This remarkable efficiency underscores the fact that a lithium-ion battery equipped electric motor is at least three times more energy-efficient than a gasoline-powered internal combustion engine. Furthermore, a significant portion of the energy in gasoline (approximately 34 kilowatt-hours) is dissipated as unproductive heat. Consequently, Lithium-ion batteries hold the promise of substantially contributing to the proliferation of sustainable transportation through electric vehicles, thereby reducing environmental risks. Additionally, Lithium-ion batteries are being actively explored for integration into smart and green grid energy storage systems, ensuring effective management of intermittent energy generation, transmission, and distribution, which aligns with the overarching goals of sustainable living. Notably, in recognition of the profound impact of Lithium-ion batteries on modern society, the Nobel Prize in Chemistry for 2019 was awarded to John

B. Goodenough, M. Stanley Whittingham, and Akira Yoshino.

The remarkable efficiency of lithium-ion batteries as compact and potent power sources hinges on the intricate chemistry taking place within its individual components. Within the electrodes of a lithium-ion battery, there are active materials that possess the unique ability to store and release lithium ions through electrochemical reactions. This process is akin to other any other chemical reactions, as it harnesses the energy locked within the chemical bonds of these electrode materials, all while ensuring a controlled and precise release of this stored energy. In lithium-ion batteries, the negative electrode, known as the anode, typically relies on graphite as its active material, while the positive electrode, or cathode, can feature materials like lithium iron phosphate (LFP), nickel manganese cobalt oxide (NMC), or lithium cobalt oxide (LCO). Copper and aluminium serve as the current collectors for the anode and cathode within a lithium-ion battery, with the active electrode materials coated alongside conducting additives and a polymeric binder. These components collectively work to improve electron transport and enhance electrode stability. The movement of lithium ions between the anode and cathode is what generates electrical energy in the battery. It's essential to highlight that the choice of cathode material exerts a significant influence on battery performance, directly impacting factors like energy density, power output, and cycle life. For instance, NMC is a versatile cathode material that balances energy density and power capability, making it one of the leading contenders for electric vehicle applications. Lithium Iron Phosphate (LFP) is known for its safety and long cycle life, making it suitable for applications where durability and stability are essential, e.g., stationary energy storage. However, recently LFP is also finding its presence in electric vehicles since it reduces the dependency on costly metals like nickel and cobalt. Lithium Cobalt Oxide (LCO) offers high energy

density but is more sensitive to thermal and overcharging conditions. It is often used in applications where high energy density is critical, like consumer electronics.

In conjunction with the active electrode materials, lithium-ion batteries crucially depend on another vital element known as the electrolyte. The typical composition of the electrolyte in lithium-ion batteries includes lithium salt dissolved in organic solvent (often a mixture of organic solvents). Its primary role is to facilitate the transfer of lithium ions between the electrodes during both the charging and discharging phases. Additionally, the electrolyte serves as a physical separator between the electrodes of the lithium-ion battery, often employed alongside a porous separator

material, such as a thin layer of porous polymer or glass-fiber, in commercial battery designs. The use of a liquid electrolyte in a lithium-ion battery has both advantages and disadvantages, with one of its significant drawbacks being its high flammability, which poses safety risks. Hence, in addition to possessing high ionic conductivity, lithium-ion battery electrolytes must exhibit exceptional electrochemical, chemical, and thermal stability. In simpler terms, an electrolyte should remain inert, refraining from reacting with either the cathode or the anode during the operation or storage of lithium-ion batteries. Any chemical interactions with the electrodes can result in a decline in performance or, in the worst-case scenario, pose the risk of fire accidents.

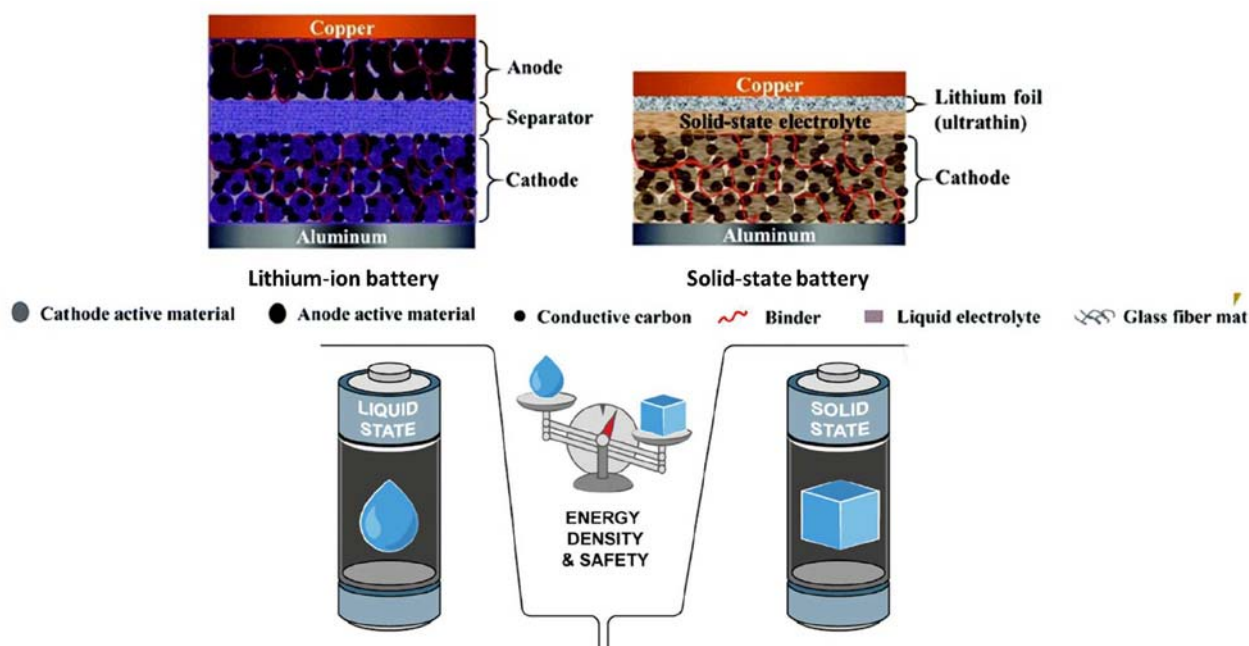


Illustration of state-of-the-art lithium-ion batteries and solid-state batteries (top) and comparison of their energy density (bottom) (the figures are reproduced under the terms of the CC BY 4.0 DEED license (<https://creativecommons.org/licenses/by/4.0/>) from the articles *Energy Environ. Sci.*, 2021, **14**, 2708-2788 and *Adv. Energy Mater.* 2023, **13**, 2203326)

To mitigate the safety concerns linked to liquid electrolytes, the lithium-ion battery industry has shown significant interest in solid-state electrolytes. These solid materials possess ion-conducting properties, eliminating the need for flammable liquids in lithium-ion batteries. The primary contenders in solid-state battery technology are solid polymer electrolytes and inorganic solid-state electrolytes. While solid-state batteries belong to the

lithium-ion battery family, they exhibit several fundamental differences from the state-of-the-art lithium-ion batteries currently available in the market. Most notably, solid-state batteries enable the utilization of high-energy-density lithium metal electrodes as anodes, as opposed to the low-energy-density graphite commonly used. Lithium-metal anodes encounter limitations in liquid electrolyte-based lithium-ion batteries

due to the formation of dendritic lithium structures during recharging. Consequently, lithium-ion batteries employing lithium-metal anodes and liquid electrolytes are often non-rechargeable primary batteries. Replacing graphite (with a theoretical capacity of 372 m Ah/g) with a Li-metal anode (with a theoretical capacity of 3860 m Ah/g) can increase the energy density of the resulting battery by 10 times while using the same cathode materials and chemistries. This underscores the significance of solid-state electrolytes, as they have the potential to enable rechargeable lithium-ion batteries even when utilizing lithium-metal anodes. Since solid-state electrolytes are less prone to degradation during the battery operation, they can also offer longer cycle life compared to liquid electrolyte-based standard lithium-ion batteries. Solid-state batteries are indeed crucial for the next generation of electric vehicles due to their safety improvements, higher energy density, and potential for longer cycle life. However, it's worth noting that their full commercialization may still require another decade or possibly even more to overcome technical challenges and achieve widespread adoption in the automotive industry.

In the wake of Tesla's success, numerous other prominent players in the automotive industry have embraced the transition towards electric vehicles and are investing significantly in battery production infrastructure. Establishing giga factories for battery manufacturing is a crucial component of their strategy

to secure a reliable battery supply for the surging demand in the electric vehicles market. This transition signifies a fundamental transformation within the automotive sector, as it moves towards more sustainable and environmentally friendly transportation solutions independent of traditional internal combustion engines. In order to facilitate this transition, it is crucial to uphold the supply chain of lithium-ion battery components while simultaneously managing and regulating the cost of raw materials. Given the exponential growth in demand for lithium-ion batteries across various applications, it is also imperative to explore alternative battery technologies to diversify beyond lithium-ion batteries. For instance, relying solely on lithium-ion batteries to meet all types of needs, from consumer electronics to stationary energy storage and electric vehicles, is not sustainable in light of the limited availability of lithium resources and other raw materials worldwide. Notably, emerging technologies like sodium-ion batteries are making significant strides, offering a promising avenue to reduce reliance on lithium-ion batteries. In any event, sodium-ion battery technology has not yet reached a mature stage where it can replace or function alongside lithium-ion batteries. It will likely take a few more years for sodium-ion batteries to gain the spotlight, similar to the trajectory of solid-state batteries. Overall, the outlook for battery technology is promising, and ongoing industrial advancements are positioned to usher in transformative changes, much like how the semiconductor industry revolutionized the world over the last three decades.

BREAKING CAPACITY OF CIRCUIT BREAKERS

The rate of rupturing capacity of the Circuit Breaker to be installed at any new substation or switch yard shall be at least 25% higher than the calculated maximum fault level at the bus to take care of the increase in short circuit levels as the system grows. The rated breaking current capability of switchgear and breakers to be installed at different voltage levels, base round available capacities of the breakers, shall be:

11/33 kV	25 kA (for 1 Sec.)
66 kV	31.5 kA (for 1 Sec.)
110/132 kV	31.5 kA (for 1 Sec.)
220 kV	40 kA (for 1 Sec.)
400 kV	40 or 50 kA (for 1 Sec.)
765 kV	40 or 50 kA (for 1 Sec.)

The Impact of Energy Consumption and Economic Growth on Carbon Dioxide Emissions in India

Dr. E Mohammed Shereef

Member, Permanent Lok Adalat [Dy. Chief Engineer (R), KSEBL]

Abstract

This paper examines the nexus of carbon dioxide emissions, energy consumption and economic growth in India. The effect of energy consumption and economic growth on carbon dioxide emissions for the period 2005-2021 was analysed using Augmented Dickey-Fuller (ADF) test, Johansen cointegration and Auto Regressive Distributed Lag (ARDL) bound test. The results shows that the energy consumption and economic growth have a positive and significant impact on carbon emissions in the long run and short run. The study reveals variables are cointegrated and that energy consumption and economic growth have a significant impact on carbon dioxide emissions.

Keywords CO2 emissions, Economic growth, Energy Consumption, GDP, Cointegration, Regression

1. Introduction

The problem of global climate change due to greenhouse gas emissions is a threat to human survival and development. The relationships between environmental pollution, energy consumption, and economic growth have been the subject of researchers' attention over the past several years. India is now the third largest energy consumer, and one of the top five percapita CO2 emitters in the world. The main reason for studying carbon emissions is that carbon emissions play an important role in the current debate on environmental protection and sustainable development. The economic growth is closely related to energy consumption as higher energy consumption leads to higher economic growth. Similarly the economic growth also has generally been tied to increasing greenhouse gas emissions. Since most of the greenhouse gases are emitted by burning fossil fuels in the form of CO2, the energy sector has a

significant role in reducing it. In energy sector, the level of emissions can be reduced by shifting attention to renewable energy sources which are environmentally friendly and enhance 'green' growth.

2. Brief Review of Literature

Global warming and climate change have been the most important environmental issues worldwide in recent decades. Few studies have been conducted to understand the relationship between energy consumption, economic growth and CO2 emissions. Studies have been conducted in different countries in different periods using different econometric methods. The empirical results of these studies are varied and sometimes conflicting. The difference is due to the different methods applied, the application of data from different countries, and the specific time period of the study. Most of the studies also showed that energy consumption and economic growth affect pollution caused by CO2 emissions (Salary et al. 2021; Samina et al.2021;Teng et al.2020). Industrial development accelerates economic growth but it also causes carbon dioxide emissions. In order to examine the factors that reduce environmental pollution in China, an empirical study was conducted using the ARDL approach with the data for the period 1980 to 2016. The findings revealed that globalization, trade openness and income contribute to environmental pollution in the long run (Pata and Caglar, 2021). The present study revisits the theme in the Indian context with a fresh perspective and provides new insights into the related literature.

3. Methodology

The objective of this paper is to analyse the interrelationship between CO2 emissions, energy consumption and economic growth for using annual data

over the period of 2005–2021. The variables used in this study are per capita carbon dioxide emissions in metric tons (CO₂), per capita real GDP at 2022 constant in Billion US\$ measuring economic growth (GDP), and per capita total energy consumption in mega joules (EC). All variables are transformed into natural logarithms (Ln) in order to address heteroskedasticity issues.

Multivariate linear regression is applied to investigate the relationship of CO₂ emission with respect to per capita energy consumption, per capita real GDP.

The following model is assumed for CO₂ emission. The regression model is

Here CO₂ represents per capita CO₂ emissions at year t , GDP denote per capita real GDP at year t and EC_t is per capita energy consumption at year t . The term μ_t represents the model error of the estimation.

The stationarity of each series was investigated using the Augmented Dickey-Fuller unit root test. The Johansen cointegration test is employed to establish whether variables are cointegrated. ADRL method is employed to determine the long run and short run cointegration of the variables.

Fig.1. Trend of CO₂ emission, energy consumption, and GDP

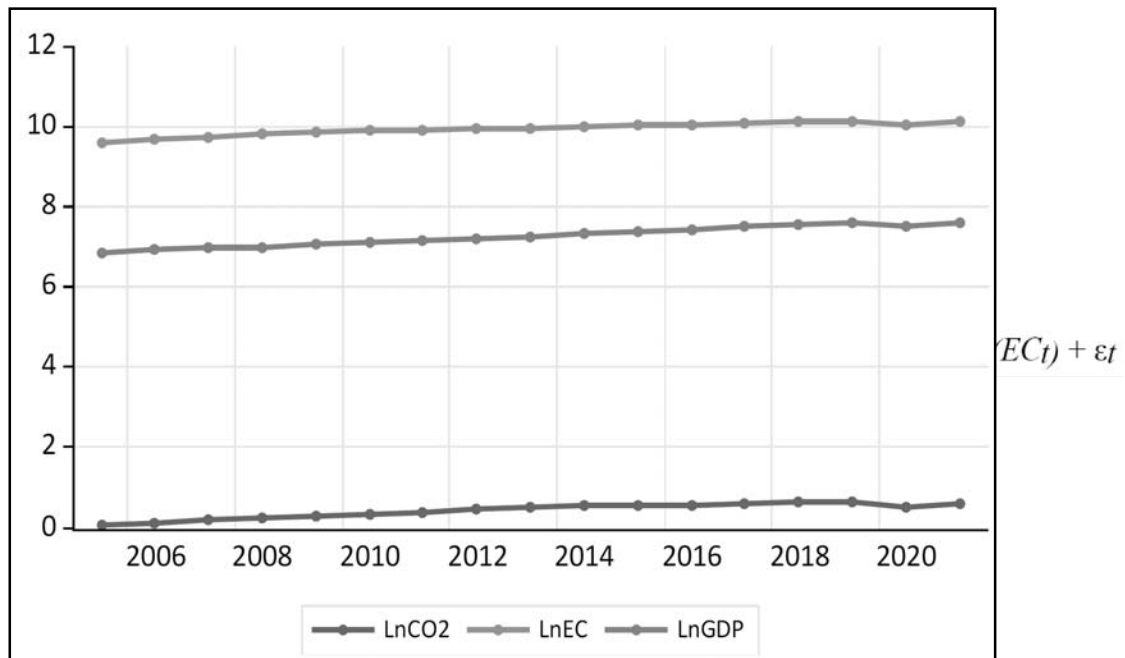


Fig.2 illustrates all scatter plots of LnCO₂ Vs. LnEC, LnCO₂ Vs. LnGDP and LnEC Vs. LnGDP

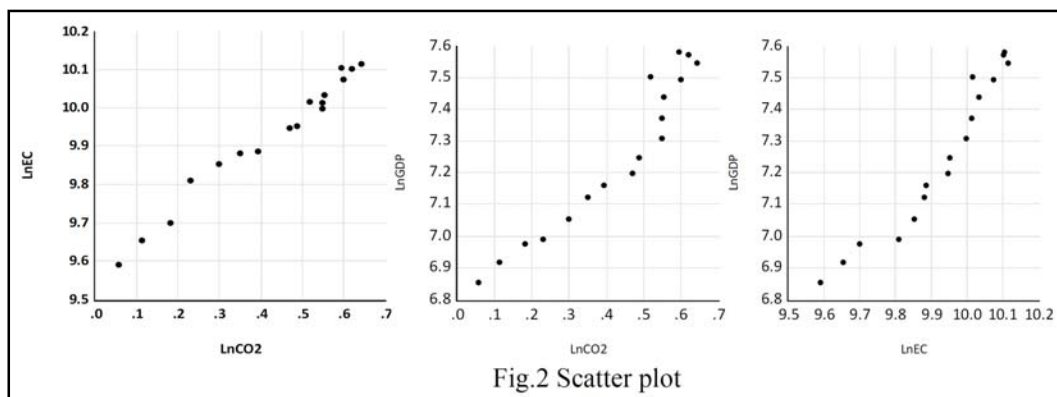


Fig.2 Scatter plot

4. Results and discussion

The summary descriptive statistics of variables CO₂, EC, and GDP are presented in Table.1. Since skewness is not zero none of the variables are not normally distributed

Table.1 Descriptive statistics

Variables	LnCO ₂	LnEC	LnGDP
Mean	0.4241	9.9249	7.2547
Median	0.4886	9.9524	7.2475
Maximum	0.6419	10.1145	7.5817
Minimum	0.5827	9.5896	6.8541
Std. Dev.	0.1864	0.1609	0.2442
Skewness	-0.6699	-0.7225	-0.1155
Kurtosis	2.1266	2.4710	1.6609
Jarque-Bera	1.8118	1.6771	1.3080
Probability	0.4042	0.4323	0.5200
Sum	7.2099	168.7228	123.3301
Sum Sq. Dev.	0.5559	0.4143	0.9539
Observation	17	17	17

The correlation matrix in Table.2 shows that there is a strong correlation between the variables CO₂, EC and GDP

Table 2. Variable correlation matrix

Variables	Ln CO ₂	LnEC	LnGDP
Ln CO ₂	1.0000	0.9891	0.9554
LnEC	0.9891	1.0000	0.9605
LnGDP	0.9554	0.9605	1.0000

4.1 Unit root test

The first step in time-series analysis is to determine whether the levels of the data are stationary. The Augmented Dickey-Fuller unit root test is performed to verify whether the three time series are stationary. The results at level and first difference are presented in Table.3

Table.3 Augmented Dickey- Fuller Test

Variable	At level			At first difference		
	t-Statistic	CV at 5%	Prob.*	t-Statistic	CV at 5%	Prob.*
Ln CO ₂	-3.828975	1.165525	0.9996	-4.394194	-3.828975	0.0211
LnEC	-3.7332	-1.999333	0.558	-4.623865	-3.759743	0.0119
LnGDP	-3.828975	-2.816487	0.2171	-3.891375	-3.759743	0.0403

The result shows that all the three series are non-stationary in their level form, but after taking the first difference the null hypothesis of non-stationarity is rejected at 5% significance level. This indicates that the first difference of variables Ln CO₂, LnEC and LnGDP are stationary.

4.2 Johansen cointegration test

Since the variables are non stationary at level and stationary at first difference, cointegration among the variables is explored using the Johansen cointegration test. The result is presented in Table.4

Table.4 Johansen Cointegration test.

No. of Hypothesized Coint. Eqs	Eigen Value	Trace Statistics			Max-Eigen Statistics		
		Trace Statistics	0.05 CV	P-Value	Max Statistics	0.05 CV	P-Value
None*	0.9993	117.7676	29.7971	0.0000*	102.0814	21.1316	0.0000*
Atmost	1 0.6084	15.6863	15.4947	0.0468*	13.1257	14.2646	0.0751
Atmost 2	0.1671	2.5605	3.8415	0.1096	2.5605	3.8415	0.1096

From the trace test and max-eigenvalue test, the null hypothesis of no cointegrating equation is rejected at the 5% significance level. The results show that there is cointegration and there exist a long run relationship among the variables LnCO₂, LnEC and LnGDP

4.3 ARDL Test

In this study, the ARDL co-integration testing is used to

ensure the robustness of the estimates and to inspect the presence of a co-integration association among LnCO₂, LnEC and LnGDP. In the ARDL model, it is assumed that the residuals have a constant variance (homoscedasticity). The heteroscedasticity in residuals is estimated using Breusch-Pagan-Godfrey LM Test and the results are shown in Table.5

Table.5 Heteroskedasticity Test

F-statistics	1.4134	Prob. F(4,11)	0.2930
Obs*	R2 5.4316	Prob. Chi-Square(4)	0.2458
Scaled explained	SS 1.3229	Prob. Chi-Square(4)	0.8575

Table.5 shows that the probability value of F-statistics and observed R₂ are 0.2930 and 0.2458 respectively which clearly exceeds 5% significance level. This means the acceptance of the null hypothesis i.e. no heteroscedasticity in residuals indicating there is homoscedasticity.

Table.6 Results of ARDL bound test.

Test statistic	Value	Significance level	Lower bound I(0)	Upper bound I(1)
F statistic	7.4817	10%	2.63	3.35
k	2	5%	3.1	3.87
C		2.5%	3.55	4.38
		1%	4.13	5

Table. 6 presents the results of AGRL Bound test. The F-statistic for the Bounds Test is 7.4817 and this clearly exceeds even the 1% critical value for the upper bound. Accordingly, the null hypothesis is rejected indicating that there is a long run relationship between the variables

4.3.2. Long run and short run estimate results

Table. 7 Long run estimate results

Variable	Coefficient	Std. Error	t-Statistic	Prob
LnEC	1.3637	0.3116	4.3765	0.0011
LnGDP	-0.2007	0.2130	-0.9425	0.3662
C	-11.6684	1.6761	-6.962	0.0000

The, empirical results in Table.7 refer that in line with the economic theories and previous empirical studies, the impact of energy consumption (EC) on carbon dioxide emission(CO₂) is positive and statistically significant at 1% level of significance. Since the coefficient of LnEC is positive, it means that it has a direct relationship with LnCO₂ in the long run. The coefficient of

LnEC is 1.36 which implies that all else being equal, 1% increase in energy consumption increase CO₂ emissions up to 1.36%

The short run estimate results are presented in Table.8 . Variables LnCO₂ and LnEC in the short run has a definite positive and significant relationship, that increase the CO₂ emissions

Table.8 Short run estimate results

Variable	Coefficient	Std. Error	t-Statistic	Prob
LnEC	0.6043	0.1648	3.6644	0.0037
LnEC(-1)	0.5568	0.1203	4.6276	0.0007
LnGDP	0.4547	0.1928	2.3587	0.0379
LnGDP(-1)	-0.5437	0.1697	-3.2035	0.0084
Coint. Eq(-1)	-0.4432	0.0718	-6.1762	0.001
R ²	0.8794			
F-Statistics	296.4933			

The speed of adjustment is 44.32%, which means statistically significant and correctly signed, signifying little control on emissions growth. R² value for short-run dynamics is 0.8794, which indicates that the independent variables represent an approximate 87% variance in the model's emission levels. The combined weight of the independent variables supported the Fstatistic to 1%.

5. Conclusion

Carbon dioxide emission is one of the main factors of climate change, which causes natural disasters and economic losses. In recent years, the relationship between economic growth, energy consumption, and carbon dioxide emissions has become an important issue for scholars and policy makers. Increased demand for energy and subsequent carbon dioxide emissions make both developed and developing countries vulnerable to the effects of global warming and climate change. Excessive energy consumption leads to high levels of CO₂ emissions and exacerbates the problem. In this paper the impact of energy consumption and economic growth on CO₂ emissions in India has been examined by using panel data over the period 2005 to 2021. The ARDL bounds test results confirm the existence of co-

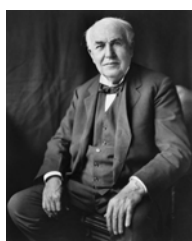
integration between the variables. The long run coefficients are estimated and found that all the variables are cointegrated indicating their long run relationship. The statistical tests were conducted using the 'Eviews' software.

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Full Name Thomas Alva Edison

Introduction Thomas Alva Edison was an American inventor and businessman. He developed many devices including the phonograph, the motion picture camera, and a long-lasting, practical electric light bulb.

Date of birth February 11th 1847

Date of death October 18, 1931 (aged 84), West Orange, New Jersey, U.S.

Education High school dropout

Occupation Inventor, businessman

Famous inventions : Phonograph, stock ticker, mechanical vote recorder, electric light, motion pictures, electric-power distribution system

Number of patents 1093



Full Name Nikola Tesla

Nikola Tesla was a Serbian-American inventor, electrical engineer, mechanical engineer, physicist, and futurist best known for his contributions to the design of the modern alternating current (AC) electrical supply system.

Date of birth July 10th 1856

Date of death 7 January 1943 (aged 86), Manhattan, New York, USA

Education Dropped out of Higher Real Gymnasium Graz University of Technology

Occupation Electrical engineering, mechanical engineering

Famous inventions : AC electrical supply system, radio transmitter, Tesla Coil

Number of patents At least 278

Smart Meters for a Smarter Grid

Edited by

Dr M. Krishnakumar

Assistant Engineer, KSEBL

Introduction

A smart meter is an electronic device that records information of electric energy such as consumption, voltage levels, current, and power factor and communicates the information to the consumer and to the suppliers. This advanced metering infrastructure (AMI) differs from automatic meter reading (AMR) in that it allows two-way communication between the meter and the supplier.

History

The first smart meter was produced in 1977. Since this system was developed pre-before the introduction of Internet, it utilized the IBM series 1 mini-computer. The installed base of smart meters in Europe at the end of 2008 was about 39 million units. As of January 2018, over 99 million electricity meters were deployed across the European Union, with an estimated 24 million more to be installed by the end of 2020. The European Commission DG Energy estimates the 2020 installed base to have required •18.8 billion in investment, growing to •40.7 billion by 2030, with a total deployment of 266 million smart meters.

By the end of 2018, the U.S. had over 86 million smart meters installed. In 2017, there were 665 million smart meters installed globally

Benefits to Consumers and Suppliers

A smart meter provides detailed information on consumption of electricity and also increase knowledge about the status of the electricity grid, which improves its performance and the quality of service for customers.

Non-smart electrical meters only measure total consumption, providing no information of when the energy was consumed. Smart meters provide a way of measuring electricity consumption in almost real-time. This allows utility companies to charge different prices for consumption according to the time of day and the

season. It also facilitates more accurate cash-flow models for utilities. Since smart meters can be read remotely, labour costs are reduced for utilities.

Smart metering offers many benefits to customers. These include, An end to estimated bills, which solves many worries of consumers, It help consumers to manage their energy consumptions and reduce their energy bills. Electricity pricing usually peaks at certain times of the day and the season. Billing customers at a higher rate for peak times encourages consumers to adjust their consumption habits which in turn flatten the load curve which can be very beneficial for the suppliers as well as consumers. An academic study based on existing trials showed that electricity consumption on average is reduced by approximately up to 5% when provided with real-time feedback.

Another advantage of smart meters that benefits both customers and the utility is the monitoring capability they provide for the whole electrical system. As part of an AMI, utilities can use the real-time data from smart meters measurements related to current, voltage, and power factor to detect system disruptions more quickly, allowing immediate corrective action to minimize customer impact such as blackouts. Smart meters also help utilities understand the need power grid. This greater understanding facilitates system planning to meet customer energy needs while reducing the burden of additional infrastructure investments, which in turn reduces energy cost increases

Now a days scheduling is much more challenging activity as the renewable generation sources make up a good proportion of the energy mix, the real-time data provided by smart meters allow grid operators to schedule renewable energy onto the grid in order to balance the networks. As a result, smart meters are considered an essential technology towards green energy system.

Characteristics of smart meters

The meter traditionally used to measure energy consumption had functions that were essentially measuring and storing the total accumulated value.

Smart meters incorporate a *power-limiting circuit breaker*, which means it does not have to be installed inside the customer's own electrical panel, improving the response and capacity to act. They also have a telecommunications interface for remote communication between the central systems and the meter, allowing remote reading and operations, such as sending new tariff tables, modifying the parameters associated with the contracts and the configuration of the meter itself, as well as the operation of the internal switch. The above-mentioned significant technological developments enable smart meters to perform new functions such as;

Multiple energy registers and multiple tariffs

Smart meters store energy consumption on an hourly or even more detailed basis. This makes it possible to bill the consumption in each time period at a different tariff, so each customer can choose the option that allows them to minimise their bill according to their consumption profile. It is also a useful tool to encourage responsible consumption.

Simultaneous management of several contracts

Distributed Energy Resources are an important tool in the fight against climate change and smart meters are key to facilitating the integration of renewable energy, especially photovoltaic power from small installations in households. prosumers can, thus, enjoy the advantages of generating their own energy while retaining the advantages of remaining connected to the electricity distribution grid. In this smart meters, enables the simultaneous management of energy purchase and sale contracts.

Multiple records of supply quality events

In addition to storing energy consumption measurements, smart meters allow real time information to be collected

on the status of the electricity grid. Including making it possible to identify *supply interruptions, inefficient voltages and incorrect connections*. Thus, significantly improving the quality of supply and the time it takes to locate and replace faults, again benefiting customers.

All the aforementioned functionalities utilize the communication capabilities. They are available for central services to process automatically and for customers to view them on different devices.

In short, the characteristics of smart meters make it possible to provide a superior service to customers, improving the quality of supply and offering a multiple new feature. so that the customer is able to control and optimise their electricity consumption.

The future of smart meters

The new generations of meters will have additional features, including:

Ability to provide information to customers in near real time either through central systems or through a communications channel

Increase in measured network parameters and measurement frequency, improving LV network management: helps to improve planning processes, additional events, voltage curves, etc.

Distributed processing capability (edge computing), processing the measurement locally in much greater detail and enabling additional benefits like detection of distributed generation or electric vehicles, load disaggregation, demand management, etc.

Conclusion

The smart meter is at the heart of the transformation of the electricity grid into a smart grid. The data collected from these devices is enabling the use of other digital technologies, such as edge computing, cloud computing, artificial intelligence and big data, for network operation and exploitation, thus improving the customer experience and helps a knowledge-based grid management.



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Audience: Practising Engineers, Researchers, Students, Faculty Members, and Professionals.

Energy Efficiency

Efficient energy use is the goal to reduce the amount of energy required to provide products and services. For example, insulating a home allows a building to use less cooling energy to achieve and maintain a comfortable temperature. Installing fluorescent lights, LED lights or natural skylights reduces the amount of energy required to attain the same level of illumination compared with using traditional incandescent light bulbs. Improvements in energy efficiency are generally achieved by adopting a more efficient technology or production process or by application of commonly accepted methods to reduce energy losses. Energy efficiency and renewable energy are said to be the *twin pillars* of sustainable energy policy and are high priorities in the sustainable energy hierarchy. In many countries energy efficiency is also seen to have a national security benefit because it can be used to reduce the level of energy imports from foreign countries and may slow down the rate at which domestic energy resources are depleted.

Indian Power Sector

Total Installed Capacity (As on 31.05.2023) - Source : Central Electricity Authority (CEA)

INSTALLED GENERATION CAPACITY (SECTOR WISE) AS ON 31.05.2023

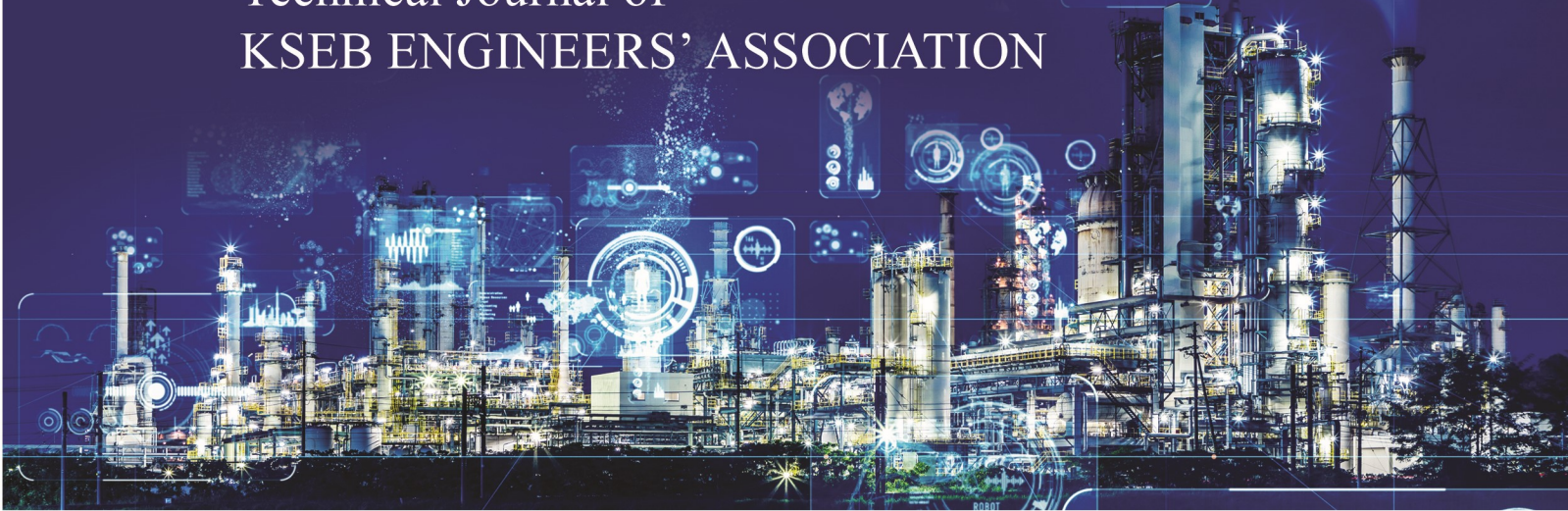
Sector	MW	% of Total
Central Sector	1,00,055	24.0%
State Sector	1,05,726	25.3%
Private Sector	2,11,887	50.7%
Total	4,17,668	

Installed GENERATION CAPACITY(FUELWISE) AS ON 31.05.2023		
CATAGORY	INSTALLED GENERATION CAPACITY(MW)	% of SHARE IN Total
Fossil Fuel		
Coal	205,235	49.1%
Lignite	6,620	1.6%
Gas	24,824	6.0%
Diesel	589	0.1%
Total Fossil Fuel	2,37,269	56.8 %
Non-Fossil Fuel		
RES (Incl. Hydro)	173,619	41.4%
Hydro	46,850	11.2 %
Wind, Solar & Other RE	125,692	30.2 %
Wind	42,868	10.3 %
Solar	67,078	16.1 %
BM Power/Cogen	10,248	2.5 %
Waste to Energy	554	0.1 %
Small Hydro Power	4,944	1.2 %
Nuclear	6,780	1.6%
Total Non-Fossil Fuel	179,322	43.0%
Total Installed Capacity	4,17,668	100%

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India has set ambitious clean energy targets with the implementation of sustainable alternatives to fulfil its energy requirements. The aim is to increase non-fossil energy capacity to 500 GW by 2030, meet 50 percent of its energy requirements from renewable energy by 2030, and achieve the Net Zero emissions target by 2070.

This call to action will transform India's powersector, accelerating the pace of reforms and adoption of new technologies and systems.



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