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Page: 615-619

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IEC 2019

THEME THE ROLE OF ENGINEERING AND
TECHNOLOGY IN SUSTAINABLE DEVELOPMENT

BOOK of
PROCEEDINGS



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- Kinetic Modelling and Error Analysis of the Bioremediation of Used Motor Oil Contaminated Soil Using Palm Bunch Ash as Stimulant
Abdulyekeen, K. A., Allyu, A., Abdulkarim, A. Y., Salis, A., & Abdulkarim, A. S. 99 – 103
- Quantitative Risk Analysis for Communication Satellite Payload
Babadoko, D. M., & Ikechukwu, A. D. 104 – 113
- Characterization and Grading of South Eastern Nigerian Grown *Mangifera Indica* Timber in Accordance with British Standard 5268
Mbakwe C.C., Aguwa J.I., & Oritola S.F. 114 – 120
- Characterization of Palm Kernel Shell as Lightweight Aggregate in Concrete Production
Sunday I.O., Aguwa J.I. & Auta S.M. 121 – 125
- Integrated Geophysical Investigation of the Failed Portion of Minna-Zungeru Road, Minna Niger State
Osheku, G. A., Salako, K. A., & Adetona, A. A 126 – 132
- Partial Replacement of Fine Aggregate with Waste glass in Concrete made from Bida Natural Aggregate
Alhaji B., Kolo, D. N., Abubakar M., Yusuf A., Abdullahi, A. and Shehu, M. 133 – 137
- Assessment of the Compressive Strength of Concrete Produced with Fine Aggregate from Different Locations in Minna
Aminulai, H. O., Abdullahi, A., Abdulrahman, H. S., Alhaji, B., Joseph, O. F., Aliyu, S. Y. 138 – 143
- Response Surface Optimisation of the Adsorption of Cu (II) from Aqueous Solution by Crab Shell Chitosan
Babatunde E. O., Akolo S. A., Ighalo J. O. & Kovo A. S. 144 – 151
- The Linear Transformation of a Block Hybrid Runge-Kutta type Method for Direct Integration of First and Second Order Initial Value Problem
Muhammad, R., Yahaya, Y.A., & Abdulkareem, A.S. 152 -154
- Groundwater Potential Mapping in Bosso Local Government Area, Niger State, Nigeria
Abubakar, U.B. & Muhammed, M. 155 – 159
- Optimization of Synthesis Parameters of Silica from Bentonite Clay Using Acid Leaching
Ogwuche, A. S., Auta, M., & Kovo, A. S. 160 – 163
- Chemical and Mineralogical Characterization of Locally Sourced Nigerian Clay
Sumanu, O. M., Dim, P.E. & Okafor, J. O. 164 – 167
- Production and Optimization of Bioethanol from Watermelon Rind using *Saccharomyces Cerevisiae*
Igbonekwu, C. A., Afolabi, E. A., Nwachukwu, F.O. 168 – 173
- Use of Carbide Waste as a Mineral Filler in Hot Mix Asphalt
Murana, A.A. & Musa, Y. 174 – 182
- Review of Bio Oil Upgrading from Biomass Pyrolysis
Abdullahi, M. A, Garba, M. U, Eterigho E. J, & Alhassan, M. 183 – 192



3rd International Engineering Conference (IEC 2019)
Federal University of Technology, Minna, Nigeria



Optimization study of Deacetylation Process in the Synthesis of Chitosan from Red Shrimp Using Response Surface Method <i>Ananda, A. S, Jimoh, A. & Ibrahim, A.A.</i>	193 – 204	1
Optimisation Study on the removal Pb(II), Cd(II) and Ni(II) from Pharmaceutical Wastewater using Carbonized African Giant Snail Shell (<i>Archachatina marginata</i>) as an Adsorbent. <i>Olanipekun, O., Aboje, A. A, Auta, M.</i>	205 – 215	7
Ground Electromagnetic Prospecting for Potential Ore Mineralisation Zones in Tsohon- Gurusu Area of Minna, North Central Nigeria <i>Ogale, O. D, Rafiu, A. A., Alhassan, D. U., Salako K. A., Adetona A. A. & Unuevho C.</i>	216 – 222	6
Magnetic and Geoelectrical Prospecting for Gold Mineralisation Within Tsohon-Gurusu Area, Part of Sheet 164 Minna, North-Central Nigeria <i>Omuigbe, L. E, Salako, K. A, Unuevho, C.I, Rafiu, A. A, Alhassan, D. U, Ejepu, J. S, & Adetona, A. A.</i>	223 -228	3
Road Stabilization Using Cold Bitumen for Low Traffic Road <i>Kolo S. S., Jimoh, Y. A., Alhaji, M.M, Olayemi, J. & Shehu, M.</i>	229 – 233	2
Sawdust Ash Stabilization of Weak Lateritic Soil <i>Kolo S. S., Jimoh Y. A., Yusuf I. T, Adeleke O. O., Balarebe, F. & M. Shehu</i>	234 – 238	0
Radio Refractive Index and Refractive Index Gradients Variation in a Tropical Environment <i>I.M. Tukur, K.C. Igwe & J.O. Eichie</i>	239 - 243	0
Vocational and Technology Education: A Viable Entrepreneurship Tool for Rapid Economic Growth <i>Kareem, W.B., Abubakar, H.O. (Mrs.), Onuh, J., Abdulrahman, T.S., Abdullahi S.M.</i>	244 – 249	5
A 2-Step Hybrid Block Backward Differentiation Formula for the Approximation of Initial Value Problems of Ordinary Differential Equations <i>Akintububo, Ben.G & Umaru Mohammed</i>	250 – 254	3
Significant Delay Factors Affecting Completion Time of Public Sector Construction Projects in Niger State <i>Mamman, J. E., Abdullahi, A. H., Isah, L. M.</i>	255 – 260	7
Communication Frequency and Effectiveness on Construction Sites in Abuja, Nigeria <i>Mamman, J.E., Abdullahi, A.H. & Isah, M.L.</i>	261 – 269	
Contribution of Quality Management Practices towards Building Collapse in Nigeria <i>Yunusa, H., Makinde, J. K., & Oke, A. A.</i>	270 – 277	
Assessment of Ethical Practices at Different Stages of Public Housing Delivery in Nigeria <i>Oluwadare, D. O. & Idiake, J. E.</i>	278 – 285	
Participation of Female Quantity Surveyors in the Nigerian Construction Industry <i>Nnamoko, C. E</i>	286 – 292	
Performance Evaluation of WUPA Wastewater Treatment Plant Idu-Industrial Area, Abuja <i>Saidu, M., Adesiji, A. R., Asogwa, E.O., Jiya, A.M. & Haruna, S.I.</i>	293 – 296	
Evaluation of Strength Characteristics of Compacted Deltaic <i>Chikoko</i> Clay Stabilized with Rice Husk Ash <i>T.W.E. Adejumo & B. B. Olanipekun</i>	297 – 303	



Empirical Impact Evaluation of Sales Promotional Mix on Sachet -Water Product Distribution on Enterprise Performance: A Survey of Selected Sachet- Water Outfits in Niger State
Adima Julius Osaremen

Assessing the Level of Readiness to Adopt Building Information Modelling (BIM) Amongst Built Environment Professionals In Selected Northern Nigerian States
Abubakar, I. T. & Oyewobi, L. O.

Design and Implementation of an SMS-based dynamic matrix LED Display Board
Habibu, H., Chukwu, E. C., Latifa, Y., Haris, M. Y. & Okosun, O. E.

An Improved User Pairing, Subchanneling, and Power Allocation Algorithm For 5G Noma System.
Muhammad Z.Z., Tekanyi A.M.S., Abubilal K.A., Usman A. D., Abdulkareem H. A. & Kassim A. Y.

Automation of Agricultural Machinery Operation Systems; An Imperative for Sustainable Development
Bala Ibrahim

Electricity Generation using Locust Bean Waste and Coal in a Molten Carbonate Direct Carbon Fuel Cell
Yakubu E., Adeniyi, O.D., Alhassan M., Adeniyi, M.I., Uthman H., and Usman A.A.

Design of a Programmable Solid State Circuit Breaker
Ajagun, A. S., Abubakar, I. N., Yusuf, L. & Udochukwu P. C.

Design of an Arduino Based RFID Line Switching Using Solid State Relay with Individual Phase Selection
Ajagun, A. S., Yusuf, L., Abubakar, I. N. & Yusuff, S. D.

Development of an Improved Adaptive Hybrid Technique to Mitigate Cross-Tier Interference in a Femto-Macro Heterogeneous Network
Kassim, A. Y., Tekanyi, A. M. S., Sani, S. M., Usman, A. D., Abdulkareem, H. A. & Muhammad, Z. Z.

The Level of Awareness of Electrical Safety Among Energy Users in Sokoto State
Umar, A., Abubakar, I. N., Yusuf, H. M. & Okosun, O. E.

Phytoremediation of Soil Contaminated with Brewery and Beverage Effluents using *Cynodon dactylon*
Mustapha, H., Ehichoya, C. S & Musa, J. J

Application of Dreyfus Model of Skills Acquisition in Curbing Youth Unemployment Among the Motor vehicle Mechanic Students' in Nigeria
Aliyu Mustapha, Abdulkadir Mohammed, Abubakar Mohammed Idris & Benjamin Oke

A Numerical Analysis of Convective Heat Transfer Rate from A Wavy Fin Projecting Horizontally From A Rectangular Base
Okon, J. O.

Towards A Hybrid MQTT-COAP Protocol for Data Communications In Wireless Sensor Networks
Nwankwo, E. I, Onwuka, E. N & Michael, D.

Toward a Hybrid Technique for Friends Recommendation System in Social Tagging
Usman Bukar Usman

Towards A Model for Aspect Based Sentiment Analysis of Online Product Review
Abdulganiyu, O. H. & Kabiru, U.

304 - 312

313 - 323

324 - 329

330 - 337

338 - 343

344 - 349

350 - 354

355 - 361

362 - 370

371 - 376

377 - 384

385 - 390

391 - 396

397 - 403

404 - 410

411 - 418



3rd International Engineering Conference (IEC 2019)
Federal University of Technology, Minna, Nigeria



Parametric Oscillations in Electric Oscillatory System <i>Enesi A. Y., Ejlogu. E. C.</i>	419 – 423
Fenestration Effect on the Adequacy of Classroom UDD <i>Azodo, A. P., Onwuballli, C. & Mezue T. C.</i>	424 – 431
Prediction of Upper Limb Functional Ability in Post-Traumatic Patients Using Machine Learning. <i>Zalyanu Nuhu, Yeong Che Fai, Elijah David Kure, Ibrahim B. Shehu, Mahmoud Mustapha, Rabiu Al-Tanko & Khor Kang Xiang</i>	432– 441
Arduino Based Automatic Irrigation System <i>Ibrahim Bashir Shehu, Zayyan Nuhu & Rbiu Altanko Ummaisha</i>	442 – 448
Production and Application Potentials of Sugarcane Bagasse Reinforced Polymer Composites for Acoustic Control <i>Sanda Askira Damboama</i>	449 – 456
Electromagnetic Field analysis of a Single-phase Induction Motor based on Finite Element Method <i>Omokhaje J. Tola, Edwin A. Umoh, Enesi A. Yahaya, Chika Idoko, Ayo Imoru</i>	457 – 463
Parameter Investigation and Analysis for Elite Opposition Bacterial Foraging Optimization Algorithm <i>Maliki, D, Muazu, M.B, Kolo, J.G, & Olaniyi, O.M.</i>	464 – 471
Multi-Access Edge Computing Deployments for 5G Networks <i>Masudi, I. O, Abolarinwa, J, & Zubair, S.</i>	472– 479
Suitable Propagation Models for 2.4 GHz Wireless Networks: Case Study of Gidan Kwano Campus, FUT MINNA. <i>Ogunjide, S. B., Usman, A. U., & Henry, O. O.</i>	480 – 488
A Survey on Mobile Edge Computing: Focus on MEC Deployment, Site Selection Problems and Application Scenarios. <i>Atolagbe, M. I, Osanaiye, O.</i>	489 – 496
Influence of Processing Techniques and Packaging Materials on Anti- Nutritional Properties of Soybean Flour <i>Orheva, B. A., Anehi, A. & Obasa, P. A.</i>	497 – 503
Prospects and Challenges of Off-Grid Power Generation For Rural Communities in Nigeria – Theoretical Perspective <i>Dangana Audu & Ikechuku A. Diugwu</i>	504 – 509
Spectrum Occupancy Measurement in the VHF Band- Results and Evaluation in the Context of Cognitive Radio <i>Ajiboye, J.A, Adegboye, B.A, Albinu, A.M, Kolo, J.G</i>	510 – 514
Modelling and Simulation of Adaptive Fuzzy-PID Controller for Speed Control of DC Motor <i>Timothy Onyechokwa, Adegboye B. A. & A.S. Mohammed</i>	515 – 520
Implementation of Remote Patient Monitoring System using GSM/GPS Technology <i>Umar Abdullahi, Salihu Aliyu Oladimeji, Waheed Moses Audu, Muslim Saidu, Manasseh Wayo</i>	521 – 527
Comparism of Adaptive Neuro Fuzzy Inference System and Support Vector Machine for the Prediction of Immunotherapy Warts Disease <i>Abisoye, B.O, Abisoye, O.A, Kehinde Lawal, Ogunwede E mmanuel</i>	528 – 536



3rd International Engineering Conference (IEC 2019)
Federal University of Technology, Minna, Nigeria



Prediction of Epileptic Seizure using Support Vector Machine and Genetic Algorithm
Abisoye, O. A, Abisoye, B.O, Ekundayo Ayobami, & Ogunwede Emmanuel

537 – 542

The Prediction of Cervical Cancer Occurrence Using Genetic Algorithm and Support Vector Machine
Abisoye, O. A, Abisoye, B.O, Ekundayo Ayobami & Kehinde Lawal

543 – 548

Performance Evaluation of Ant Lion Optimization and Particle Swarm Optimization for Uncapacitated Facility Location Problem (UFLP)
Shehu Hussaina & Morufu Olalere

550 – 558

Potential, Barriers and Prospects of Biogas Production in North- Central Nigeria
Ahonle Jennifer Eferi & Adeoye Peter Aderemi

559 – 564

Design Analysis of Manually Operated Machine for On-Row Transplanting of Paddy Rice
Ibrahim, T. M., Ndagi, A., Katun. I. M. & Anurika, U. A.

565 – 572

Investigation of Vulnerability of Oil and Gas Critical Infrastructures and Developing a Tracking Algorithm to track Malicious Attacks on the Streams
Isah, A.O., Alhassan, J.K, Idris, I., Adebayo, O.S., Onuja, A. M.

573 – 580

Optimization of Process Variables in Bio-Waste Based Activated Carbon Preparation Using Response Surface Methodology.
Onuoha, D. C., Egbe, E. A. P., Abdulrahman, A. S. & Abdulkareem, A. S.

581 – 589

Development of a Petroleum Pipeline Monitoring System for Detection, Location and Characterization of Damages in Pipes
Aba, E. N, Olugboji, O. A, Nasir, A, Oyewole, A, & Olutoye, M. A.

590 – 598

Analysis of Maximum Power Point Tracking (MPPT) Techniques under Different Atmospheric Conditions: Technical Review
Dania, D. E, Tsado, J, Nwohu, M, & Olatomiwa, L.

599 – 608

Development OF Briquette-Powered Water Distiller
Muhammadu M. M, Unugbai, J. A, Bako M. D., Abubakar J. A.

609 – 614

Impact of SVC and DG Coordination on Voltage Constrained Available Transfer Capability (VSATC)
Sadiq A. A, Adamu S. S, Abubakar I. N. & Yusuf L.

615 – 619

Construction of a Solar Powered Battery Forge
Adimula, M. G., Abubakre, O. K., Muriana, R. A.

620 – 625

Financial Assessment of the Flood Risk Preparedness of Some Selected States in Nigeria
Idachaba, A, Makinde, J & Oke, A.

626 – 631

Development of Spin Dryer Machine
Alhassan T. Yahaya & Muhammadu M. M.

632 – 641

Assessment of Quality Control Management in Sachet Water Packaging
T.J Bolaji and A.A. Abdullahi

642 – 648

Survey of Tractor Usage and Parts Breakdown in Niger State, Nigeria
Dauda, S. M., Abdulmalik M.K., Isyaku M. I., Francis A.A. & Ahmad D.

649 – 654



3rd International Engineering Conference (IEC 2019)
Federal University of Technology, Minna, Nigeria



- Development of an Inspection Methodology for Peugeot 508
Bala Dauda & James Oseni Abu 655 – 660
- Design and Fabrication of Banana Fiber Extractor machine and Performance Evaluation for the Reinforcement of Composites
Odili Kinsley Chika & Ademoh N.A. 661 – 667
- Optimisation of Biodiesel Production from Sandbox (*Hura Crepitans*) Seed Oil
Usman M., Adebayo S., Aliyu M. & Dauda, S. M. 668 – 676
- A Multi-source Broadband Radio Frequency Energy Harvester with Cascaded Diversity Combiner for Mobile Devices
Ihemelandu, J. C., Onwuka, E. N., David, M., Zubair, S. & Ojerinde O. A. 677 – 683
- Artificial Neural Network (ANN), a Formidable Tool for Atmospheric Forecasting. A Review
Usman M.N., Aku I.G. & Oyedum O.D. 684 – 692
- Development of a Model for Generation of Examination Timetable Using Genetic Algorithm
Ahmed A., Umar B. U., Abdullahi I. M., Maliki. D., Anda I. & Kamaldeen J. A. 693 – 700
- Smart Protection of Vehicle using Multifactor Authentication (MFA) Technique
S. Aliyu, Umar Abdullahi, Majeedat Pomam, Mustapha Hafiz, Adeiza Sanusi, & Sodiq Akanmu 701 – 710
- Development of Production Frame Work to Mitigate Corrosion in Under Ground Tanks
Emenuwe Vincent & Aliyu Abdullahi 711 – 715
- Physical Property Modification of Vegetable Bio-Cutting Oil Using Garlic as EP Additive
Sanni John 716 - 719
- Soil Moisture and Nutrients Control: An Automated Design Proposal
Mustapha Mohammed, Elijah David Kure & Yusuf Mubarak 720– 727



IMPACT OF SVC AND DG COORDINATION ON VOLTAGE CONSTRAINED AVAILABLE TRANSFER CAPABILITY (VSATC)

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ABSTRACT

Rapidly increasing power demand and inadequate generation and transmission capacity have set the trends towards Distributed Generation (DG) and Flexible AC Transmission System (FACTS) aimed at sustainable power delivery. FACTS and DG are often deployed to relieve congestions, improve voltage stability, and enhance transmission capability. However, FACTS and DG placement are often achieved separately. Hence their coordination in power systems operation is paramount for improved power transfer and minimal power losses for optimal power delivery. This paper demonstrates the coordination of SVC and DG in the IEEE 14 bus network for the enhancement of Voltage Constrained Available Transfer Capability (VSATC) and power loss reduction using Multi-Objective Particle Swarm Optimization (MOPSO). Since the objectives are opposite and parallel, hence the need for the transformation of ATC to minimization, which was achieved by negating its value during dominance determination stage. Voltage constrained ATC is obtained using continuation power flow (CPF) and computed at the CPF nose curve. Result show improved ATC with increasing DG penetration level. At high DG penetration (80%), ATC improved by 6.6% while losses reduced by 18.4% when compared to SVC and DG without coordination. Also, the Pareto front of ATC versus power loss indicates parabolic like characteristics.
Keywords: CPF, DG, FACTS, MOPSO, VSATC.

1 INTRODUCTION

Utilities around the world are embracing the market-driven and deregulated framework of the electrical power supply, thereby replacing a percentage of centralised power systems operations. A key feature of deregulation is the open access to transmission infrastructure, which results in the increased volume of the power transfer transaction. The increased in transactions are often constrained by increased in transmission capacity, congestion, and voltage instability (Reddy, 2016; Sharma & Kumar, 2016; Yunfei, Zhinong, Guoqiang, & Yichu, 2015). Consequently, utilities seek to maximise the utilisation of the existing transmission infrastructure. One approach of maximising the utilisation of the existing transmission infrastructure is through optimal deployment of Flexible Alternating Current Transmission Systems (FACTS) devices. FACTS technology enables power flow re-distribution through the use of circuit parameters to relieve congestion, improve voltage stability at load centers, and enhance transmission capability (Ahmad Abubakar Sadiq, Adamu, & Buhari, 2019; Varshini & Kalpana, 2012).
On the other hand, "green politics" and issues of right of way within deregulation also prompt utilities, customers, and power system operators to prefer small capacity generators, connected to the load centers, often called Distributed Generation (DG). The financial risk of DGs is small, and possess technical potentials for ancillary

services in addition to meeting load demand (Nwohu, Olatomiwa, Ambafi, Ahmad, & Mogaji, 2017). Therefore, DGs are sited at the distribution level while large wind farms in addition to FACTS at the transmission level (Bavithra, Raja, & Venkatesh, 2016; S Kabir, Krause, Bansal, & Jayashri, 2014; S Kabir, Krause, & Haider, 2014; Shahariar Kabir, Krause, & Bartlett, 2013; Khan, Mallick, Rafi, & Mirza, 2015; Musa, Usman, & Adamu, 2013). Accordingly, a comprehensive assessment of the impacts of FACTS and DG placement in power systems operation to meet the increased power transaction is paramount. A primary index of transmission infrastructure performance and hence the viability of economic transfer transaction is the Available Transfer Capability (ATC) (A.A. Sadiq, Nwohu, & Okenna, 2014).

In (Rahman, Mahmud, Oo, Pota, & Hossain, 2016; Rahman, Mahmud, Pota, & Hossain, 2014), DSTATCOM and DG coordination are demonstrated for reactive power management to improve voltage profile and alleviate the severity of faults. Similarly, (Tolabi, Ali, & Rizwan, 2015) implements a Fuzzy - ACO approach to optimally place DSTATCOM and photovoltaic for power loss, voltage profile, and load balancing. (Venkateswarlu, Ram, & Raju, 2013) Examines the impacts of SVC and DG to increase network loading level and Voltage Stability Constrained ATC (VSATC) using Newton's Raphson (NR) power flow while (Mahdad & Srairi, 2016) uses adaptive differential search algorithm to optimize the location and sizes



multiple SVC and DG for power loss reduction and voltage deviation. The studies in (Rahman et al., 2016, 2014; Tolabi et al., 2015), ignores ATC enhancement with DFACTS and DG coordination. Although (Venkateswarlu et al., 2013) considered VSATC as critical loading factor, however, the computation of VSATC at the point where NR load flow fails to converge is an infeasible operating condition and the power balance equality constrained is violated; in addition, SVC and DG placement were not optimal but only based on the identified weak bus. In (Mahdad & Srairi, 2016), while a differential search algorithm was used, it did not consider ATC as an objective. This paper, therefore, demonstrates the coordination of SVC and DG in the IEEE 14 bus test network, for the enhancement of VSATC and power loss reduction using Multi-Objective Particle Swarm Optimization (MOPSO).

2 METHODOLOGY

2.1 SVC MODELING

At steady-state operation, the static var compensator (SVC) acts as a source or absorber of VAR. The SVC is therefore modelled as positive or negative load depending on whether it is absorbing or injecting reactive power respectively (A A Sadiq, Adamu, & Buhari, 2019; Venkateswarlu et al., 2013). The equivalent reactive load at the SVC installed bus is given by equation (1) while the modified residual Var is expressed by the equation (2). SVC capacity is constrained according to the equation (3).

$$Q_i^{new} = Q_i^{old} \pm Q_{svc} \quad (1)$$

$$\Delta Q_i^{new} = [(Q_{i,g} - Q_{i,d}) - Q_p^{cal}] + Q_{svc} \quad (2)$$

$$0 \leq Q_{svc} \leq 100 \text{ MVAR} \quad (3)$$

2.2 DG MODEL

In addition to the provision of ancillary service of local bus voltage control, DG is modelled as a generator with maximum and minimum active power capacity constrained by equation (4). Herein, to regulate the local bus voltage, the PQ bus with DG installed is modified into a PV bus.

$$5 \text{ MW} \leq P_{DG} \leq 100 \text{ MW} \quad (4)$$

The DG penetration specifies the maximum quantity of active power being injection as a percentage of the total network load (Mahdad & Srairi, 2016) and defines by the equation (5).

$$\sum_{i=1}^{ndg} P_{dg}^i \leq \mu \sum_{j \in PQ_{load}} P_{load}^j \quad (5)$$

In the equation (5), the total active power injected by DGs is a percentage of the active power demand, and the penetration is μ .

2.3 CPF FOR ATC

To solve the power flow equation, Continuation Power Flow (CPF) introduces a loading parameter λ to parameterise the power flow equations, thereby avoids singularity and ill-conditioning. The documentation of CPF for ATC assessment is given in (Ahmad Abubakar Sadiq et al., 2019), while at the CPF's nose point, the ATC evaluate to the maximum loading limit as expressed in equation (6), such that the i^{th} bus critical real power loading at the CPF nose point is expressed by the equation (7).

$$ATC = \sum_{i \in sink} P_L^{i,crit} - \sum_{i \in sink} P_L^{i,base} \quad (6)$$

$$P_L^{i,crit} = (1 + \lambda^{crit}) P_L^{i,base} \quad (7)$$

2.4 MOPSO

In this paper, the problem formulation involves two parallel and opposite objectives: ATC maximisation and minimisation of real power losses, hence a multi-objective formulation. Since the objectives are on two different fronts, there is a need to transform one of the objectives into minimisation or maximisation. Consequently, in the MOPSO algorithm, the ATC is transformed into minimisation by negating its value during the dominance determination stage. For a general minimisation problem, equation (8) defines the minimisation problem formulation of SVC and DG coordination for 2 objectives (Jumaa, Musirin, Othman, & Mokhlis, 2013; Zeinalzadeh, Mohammadi, & Moradi, 2015). The fitness vector of objectives is expressed by the equation (9), which is subject to power flows equality constraints in addition to the constraints equations (3) and (4).

$$\text{minimize } f(x, \lambda) = [f_1(x, \lambda), f_2(x, \lambda)] \quad (8)$$

$$\bar{f}(x, \lambda) = \begin{cases} -ATC = \sum_{i \in sink} P_L^{i,crit} - \sum_{i \in sink} P_L^{i,base} \\ P^{loss} = \sum_{k=1}^{nl} g_k [V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)] \end{cases} \quad (9)$$

3 RESULTS AND DISCUSSION

As a form of validation, the CPF implementation and the methodology described in (Venkateswarlu et al., 2019) were compared and shown in Figure 1. Both CPF and Newton load flow is implemented in MATPOWER 7.0. As shown in Figure 1, both NR and CPF by MATPOWER

obtains similar ATC except in the case when Gen4 and Gen5 are the only sources supplying the additional increase in load demand, which is attributed to the generators reaching their respective reactive power limits and hence the likelihood of singularity.

Observe from Figure 1 that, under the case of interest, (with SVC_DG), both approaches obtain similar ATC,

with Newton's approach having slightly higher ATC. Consequently, for the active power loss objective, CPF approach is adopted, since the ATC computation at the point where NR fails to converge present an infeasible operating condition; the power losses are therefore not valid as the constraints of power balance equation become violated.

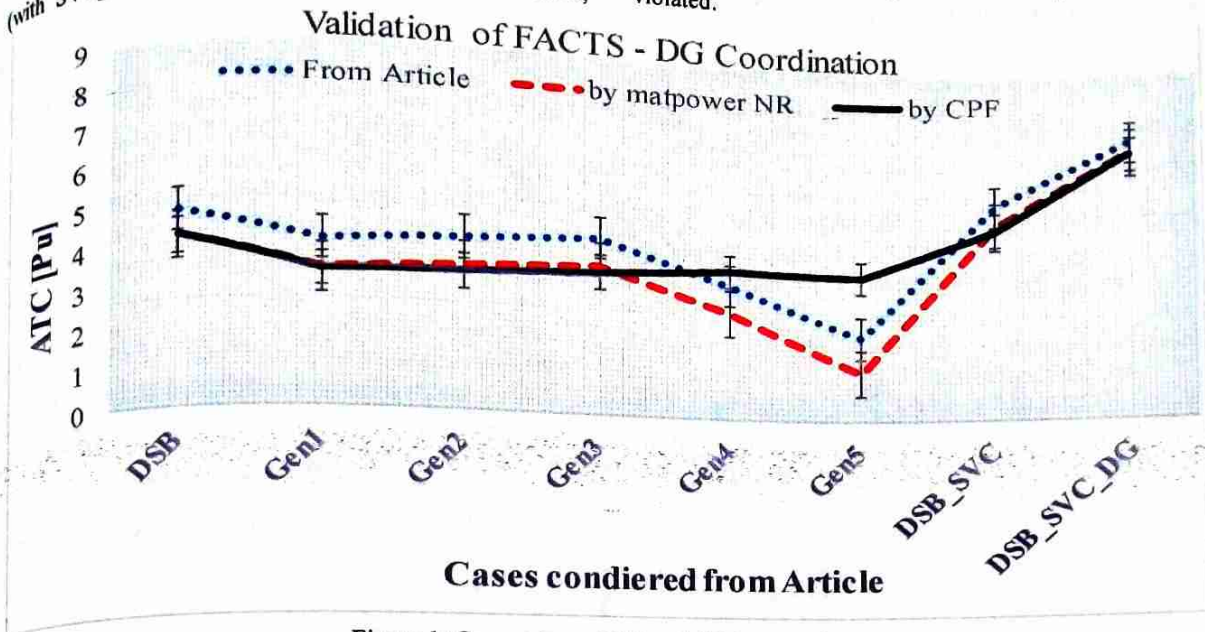


Figure 1: Comparison of NR and CPF approaches

For the multilateral power transfer transaction where all the generators are supplying the increase in load at all the load buses, Figure 2 shows the Pareto front of ATC versus Ploss

with different increasing DG penetration. The Pareto depicts a diving shape of, and the ATC increases with the increase in DG penetration.

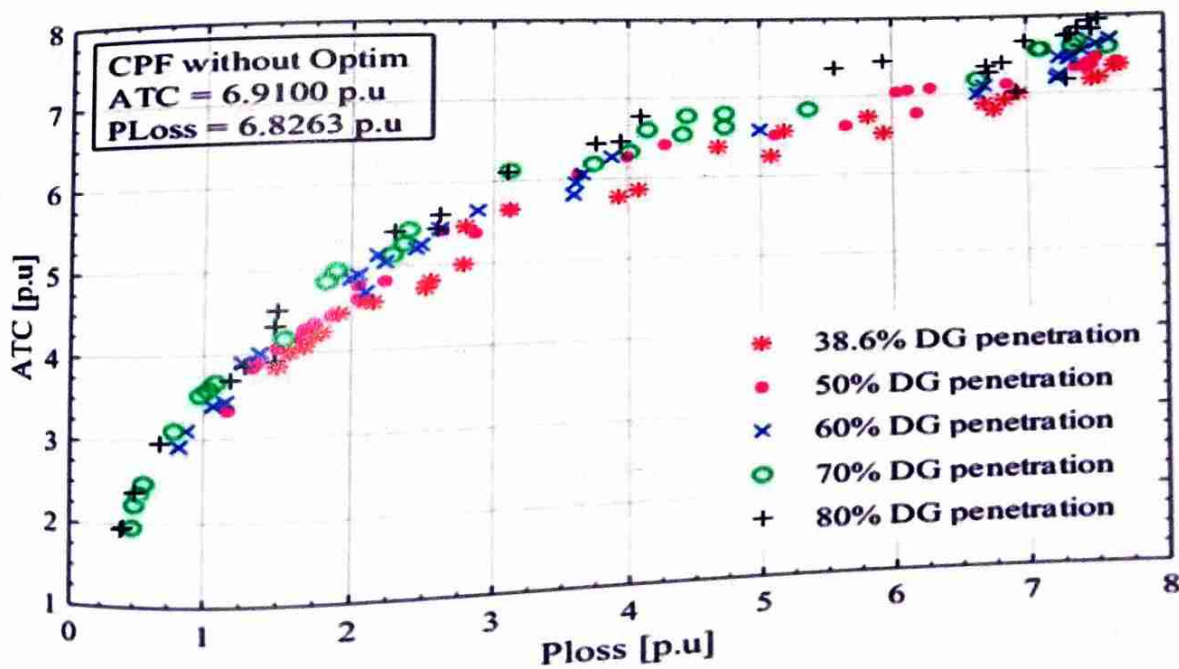


Figure 2: Pareto plot (ATC vs Ploss) for SVC & DG coordination

The Pareto front of Figure 2 with cursor values of nondominated solution within 50% and 80% is depicted in Figure 3. As shown, at 80% DG penetration, the ATC improves to 7.366 p.u with SVC and DG coordination against 6.91 p.u without coordination. Similarly, the active power losses also reduce from 6.826 p.u without coordination to 5.572 p.u with SVC and DG coordination.

At 80% DG penetration, the improvement in ATC and reduction in losses represent about 6.6% and 18.4% respectively.

TABLE I gives the selected optimal solution of the SVC and DG coordination for 50% to 80% DG penetration.

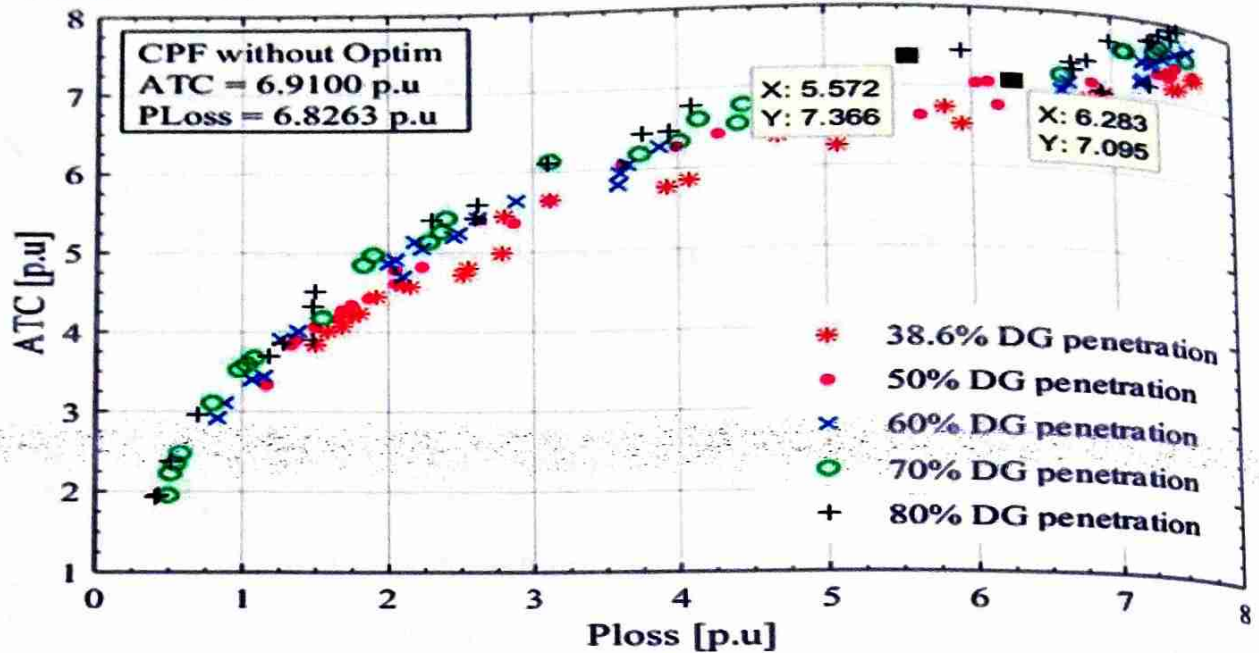


Figure 3: Pareto plot (ATC vs Ploss) with ATC and Ploss cursor values

TABLE I: SELECTED NONDOMINATED SOLUTIONS FOR VARIOUS DG PENETRATION

% DG	Fitness Values		SVC Solution		DG Solution		
	ATC [p.u]	Ploss [p.u]	SVC bus no.	SVC Size [MVAR]	DG bus no.	PDG [MW]	Vbsvc [p.u]
50	7.09	6.28	14	54.76	9	128.83	1.084
60	7.10	6.68	14	63.60	10	152.93	1.009
60	7.19	6.64	14	58.49	10	181.3	1.009
80	7.36	5.57	14	65.83	7	207.2	1.100

4 CONCLUSION

This paper demonstrates the impacts of SVC and DG coordination for the improvement of VSATC and active power losses. It can be concluded that at higher DG penetration of 80%, for the multilateral transaction where all the generators are supplying the increase in load demand, ATC improves by 6.6% while the active power losses reduced by 18.4% with SVC and DG coordination.

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