

Review: Uninterrupted Liquid Hydrogen (E-Methanol) Production framework to deliver Clean & Green Energy

Tariq MASOOD¹, Jamil Abdo²

^{1,2} Department of Engineering

101 Braddock Road, Frostburg, Maryland, 21532

Abstract—Potential broad impact: Integrating solar, wind, and conventional energy to feed the electrolyze after completion of the electrochemical process will produce two streams of O₂ and H₂. The hydrogen stream will be stored and provided with uninterrupted feed to a catalytic reactor in the presence of CO₂. It will produce E-Methanol[1]. However, this depends on these resources' reliability, cost, and availability, with the highest potential for expansion to the size needed for large-scale deployment to produce e-methanol[2]. This is known as electro-fuel, which provides electricity and fuel for electric and diesel vehicles[3][4].

As witnessed the versatility of Hydrogen in these applications highlights its significance in various industrial sectors. As the world looks towards sustainable and clean energy solutions, the role of Hydrogen is expected to grow even further [5]. However, the central part of Hydrogen is produced from fossil fuels (known as gray and brown Hydrogen) [6], and only a minimal amount of almost 4% is delivered through an electrolysis process using renewable energy to complete the chemical process [7], known as green Hydrogen. The transition to a more sustainable hydrogen economy involves scaling up the production of green Hydrogen through electrolysis and advancing technologies to improve efficiency and reduce costs associated with this process [8],[9].

Recently research indicated that production and consumption of the Green Hydrogen is the future of sustainable power delivery by replacing fossil fuel [10]. The fossil and Biomass also catalyzing the GHG (Green House Gases) with high carbon intensity, this is biggest challenge to deliver clean energy [11]. In the first instance, this research proposed an integrated Modular, which incorporate Renewable(photovoltaic) and Conventional Power sources to complete electrolysis process and its port equipment(s) to deliver uninterrupted clean Energy inform of Liquid Green Hydrogen for Electricity and to replace diesel [12][13].

Keywords—E-methanol, carbon Dioxide, Hydrogen, diesel vehicle's reliability and sustainability

I. INTRODUCTION (HEADING 1)

Green Hydrogen refers to Hydrogen produced using renewable energy sources and a process called electrolysis. Advancements in the efficiency and durability of electrolysis technologies are crucial for making green hydrogen production economically viable and competitive with other forms of hydrogen

production[14]. Pure Hydrogen is a versatile and vital resource in various industrial processes. It serves as a critical feedstock and energy carrier, playing a crucial role in different sectors such as ammonia production, petroleum refining, methanol production [15], hydrogenation processes, electronics and semiconductor manufacturing, power generation, hydrogen fuel cells in transportation[16], etc.

Figure No.1. whereas the pure hydrogen is playing vital role in petrochemical industries in the large spectrum[17]. Essentially the Hydrogen catalyzing diverse range of petrochemical industries, including the chemical (for methanol, ammonia, and polymers), refining (for hydrocracking and hydrotreating), metal processing [18], aerospace, glass, and food industries. Interest in green hydrogen as a renewable fuel is also growing. Hydrogen is still produced from fossil fuels (brown and grey hydrogen)[19]. This also produced high intensity of carbon footprints which is non-renewable. Whereas 48% produced from natural gas, 30% from light/heavy oil and 18% from coal respectively[20]. Only about 4% of green and blue hydrogen is obtained by electrolysis using either electric power from the grid or a renewable source that is green/ blue hydrogen [4]. Fig.2 also demonstrate Anthropogenetic carbon cycle for a circular economy of green Hydrogen[21].

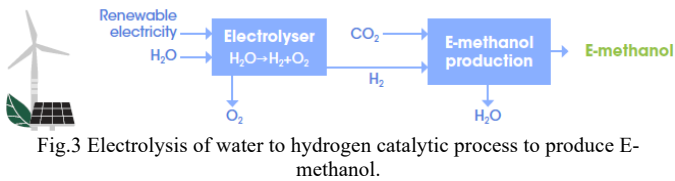
To design sustainable photovoltaic by integrating UPS (Uninterrupted Power Supply) to store and deliver energy for longer period by using lithium battery Bank [22]. Advancements in the efficiency and durability of electrolysis technologies are crucial for making green hydrogen production economically viable and competitive with other forms of hydrogen production [23]. Pure Hydrogen is a versatile and vital resource in various industrial processes [24].

II. PROJECT DESCRIPTION

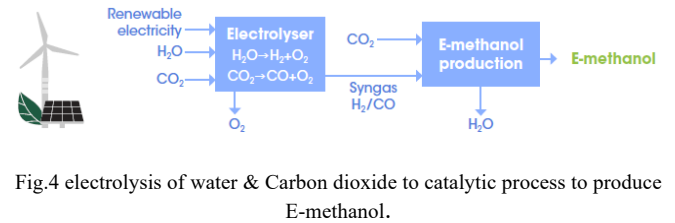
A. Electrolysis of water to hydrogen method

A liquid product is easily obtainable from CO₂ and green Hydrogen through a one-step catalytic process through an electrolysis process to feed the electrolyzer after completion of the electrochemical process will produce two streams of O₂ and

H₂ [25]. The hydrogen stream will be stored and provided with interrupted feed to a catalytic reactor in the presence of CO₂. It will produce E- Methanol. However, this depends on these resources' reliability[26], cost, and availability, with the highest potential for expansion to the size needed for large-scale deployment to produce e-methanol[27]. There are numerous ways to produce Green/Blue Hydrogen in liquid form (E-Methanol) through an electrochemical process[28]. Fig.3 indicates the most established method is to make Green/Blue hydrogen through water electrolysis using Solar/ Wind renewable electricity, followed by a catalytic reaction with CO₂ to form Green Hydrogen in liquid form (e-methanol), also known as Electro-Fuel [29].



B. Electrolysis of water and carbon dioxide to syngas method
 Fig.4 indicates another way to produce both components of Synthesis, Carbon Monoxide, and Green/Blue Hydrogen, is through electrolysis, followed by conversion of the e-methanol (a liquid form of Green Hydrogen). Higher conversion efficiency can be obtained through this process at minimum losses or effluent[30]. But this is a less developed co-electrolysis route at the lab level to produce a kilowatt scale. Conventional water electrolysis can produce up to a megawatt range [31].



C. Direct electrocatalytic synthesis method
 Fig.5 indicates the third route to produce e-methanol this process is known as the electrochemical process, the conversion of CO₂ and water to produce Methanol. However, this process has limited efficiency up to laboratory scale. In the general process, each molecule of CO₂ entering the process will exit as a methanol molecule; this requires three molecules of Hydrogen and will produce one molecule of water for each molecule of Methanol. Statistically, to deliver one tone of Methanol, for the complete process, 1.38 tone CO₂ and 0.19 tone of Hydrogen, approximately 1.7 tons of water are needed, and 10-11 MWh of electricity is required from renewable sources.

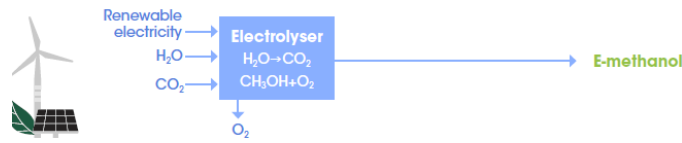


Fig.5 Direct electrocatalytic synthesis of water and CO₂ to produce E-methanol.

III. CRITICAL ASPECTS GREEN & CLEAN ENERGY OPERATIONS

- 1. Renewable Energy Integration Modular with port equipment:** Examine how solar and wind energy sources can be effectively integrated into the electrolysis process also known Chemisorption as shown Fig.5 and its port equipment(s) (1) Electrolzyer, (2) Separator of Liquid and gas, (3) Compressor, (4) Boiler, (5) Catalytic Reactor, (6) Reducing valve, (7) Absorber, (8) Stripper and (9) Distillation column Renewable and Conventional Power Utilities. Consider the variability of these renewable sources and explore methods to ensure a consistent and reliable energy supply for the electrolyzer[32].
- 2. Hybrid Renewable Systems:** Investigate the benefits of creating a hybrid renewable energy system that combines solar and wind technologies. This can enhance the overall efficiency and reliability of the system, especially in locations with variable weather conditions[33].
- 3. Electrolyzer Technology:** Explore different types of electrolyzers, such as alkaline electrolyzers, proton exchange membrane (PEM) electrolyzers, and solid oxide electrolyzers. Evaluate their efficiencies, durability, and suitability for integration with renewable energy sources[34].

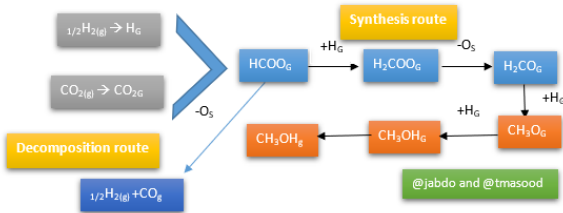


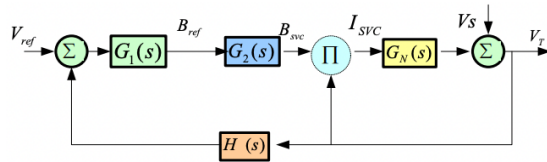
Fig.6 Chemisorption and industrial catalytic process

IV. VOLTAGE CONTROL MODEL

In the linear operating control model's Buck and Boost Converters designed to control the voltage, the AC system terminal internal voltage V and reference voltage V_{Ref} as given in the equation 3 and its parameters are also defined [26].

$$V_T = V \frac{1}{1 + G_1 G_2 HX} + V_{Ref} \frac{G_1 G_2 X}{1 + G_1 G_2 HX} \dots\dots\dots(1)$$

In the second form of operation's control model has been developed to produce the results as per defined as mathematical model. The control transfer functions which have been verified to maintain it operational credibility which has been formulated in control as given below [26].



The concept is to develop and customize the Smart control Devices to optimize its operating parameters by incorporating new control compensation control parameters. In this method, the control system has three operating and control boundaries in order to run the system successful to achieve the following [18],[19].

- Increased Power Transfer capability [23]
- Improved reliability [23]
- Improved controllability [23]
- Enhanced angle and voltage stability [23].

V. CONCLSUION & DISCUSSION

Introducing clean and green energy initiatives is essential to crafting the right policies and incentives, which is crucial to meeting the goals of carbon emission reduction, energy security, sustainability, and improvement in quality of life in the world by large. Green Energy initiatives would only happen with confidence in strong, stable, predictable, and sustained government policy. In the transport sector, especially for passenger cars, policy must focus on electromobility and support for increasing the share of EVs.

Meanwhile, Green Hydrogen fuel cells and batteries are strong candidates to serve the purpose, essentially inroads, and charging infrastructure needs to expand. Renewable Electricity and renewable fuels (Green Hydrogen and E-Methanol) will play a critical role in finding different pathways

to carbon neutrality, and public policy should create a level playing field to expand and not limit opportunities for e-methanol strong candidates to produce clean and green energy. This fuel can be yielded in regions with sufficient means of renewable Electricity, using carbon as a carrier in the form of an easily transportable liquid molecule. Advancing e-methanol manufacturing capability in diverse countries worldwide will expand energy allocation and moderate political risks. Regulation and guidelines for methanol consumed as a road transportation fuel are already operational.

Over the last 15 years, different provinces in China have instituted guidelines for methanol mixtures in transportation, going from 5% methanol in gasoline (M5) to 100% methanol (M100). China's central government has implemented a policy of commercial introduction of M100 cars, trucks, and buses.

The United Kingdom presented its Renewable Transport Fuel Responsibility scheme in 2008. Fuel branded as Renewable Fuels of Non-Biological Origin, such as e-methanol, are incentivized by awarding double credits per liter or kilogram supplied. The European Union has launched its "Green Deal" roadmap, aiming to become carbon neutral by 2050 (EU, 2020a).

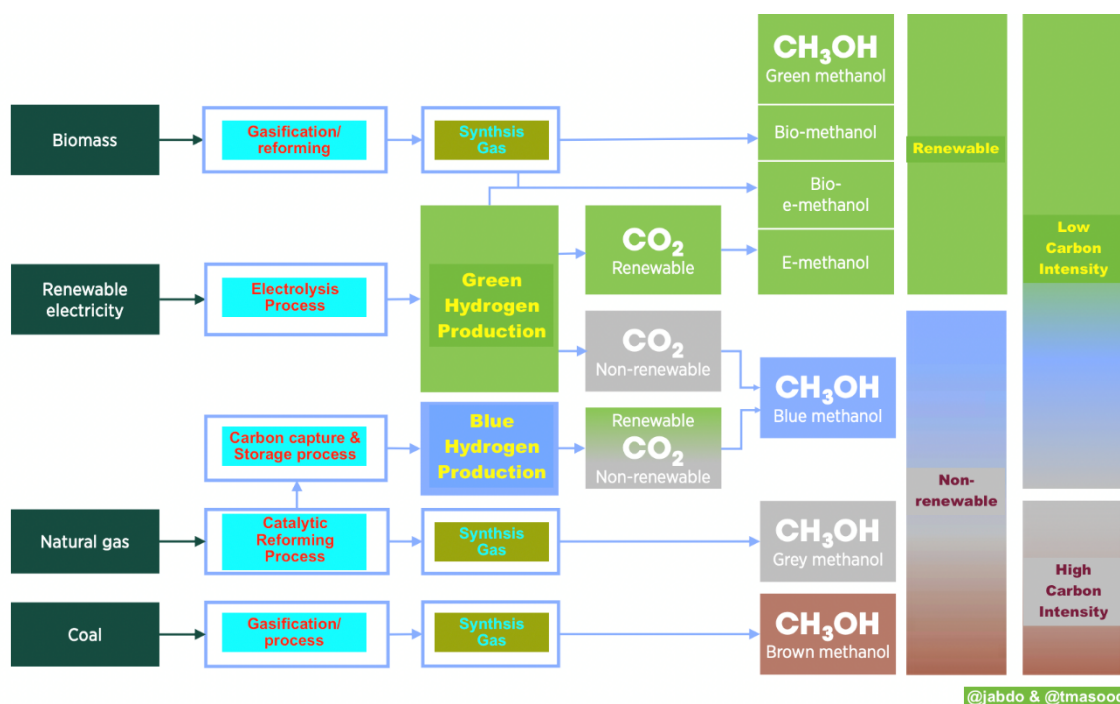


Fig.1 Types of hydrogen according to production process

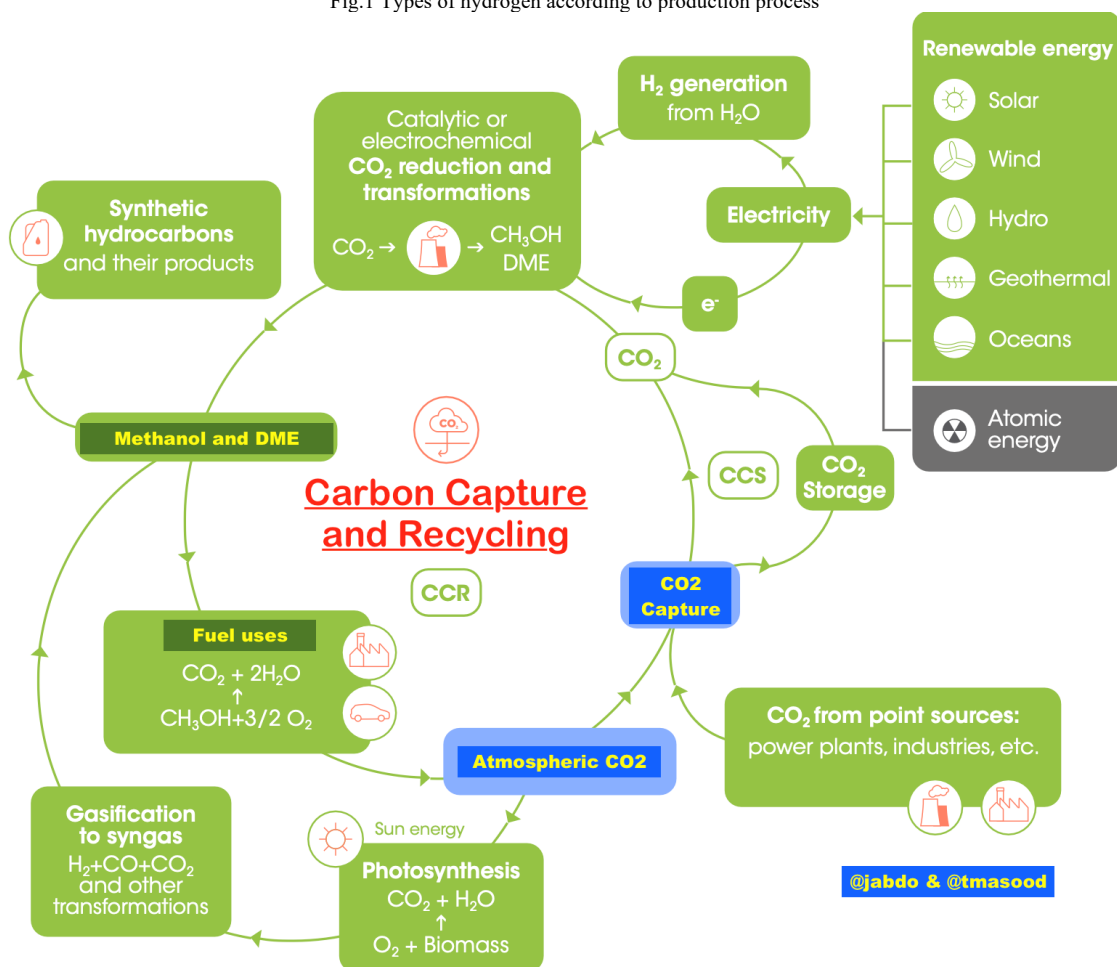


Fig.2 Anthropogenetic carbon cycle for a circular economy

VI. REFERENCES

- [1]. **ALIGN-CCUS (2020), ALIGN-CCUS project**, <http://www.alignccus.eu/> (accessed June 2020).
- [2]. **Andersson, K. and C. Márquez Salazar (2015)**, Methanol s a Marine Fuel Report, report prepared for the Methanol Institute by FCBI energy.
- [3]. **Arcoumanis, C. et al. (2008)**, “The potential of Di-Methy Ether (DME) as an alternative fuel for compression-ignition engines: A review”, *Fuel*, Vol. 87, p. 1014.
- [4]. **Atsonios, K. et al. (2016)**, “Investigation of technical and economic aspects for methanol production through CO₂ hydrogenation”, *International Journal of Hydrogen Energy*, Vol. 41, pp. 2202-2214.
- [5]. **Balcombe, P. et al. (2019)**, “How to decarbonise international shipping: Options for fuels, technologies and policies”, *Energy Conversion and Management*, Vol. 182, pp. 72-88.
- [6]. **BioMCN (2020), BioMCN**, <https://www.oci.nl/operations/biomcn/> (accessed July 2020).
- [7]. **BioTfuel (2020)**, Information obtained from a contact at BioTfuel project, July.
- [8]. **BLE (2017), Evaluations und Erfahrungsbericht für das Jahr 2016**. Biomassestrom-Nachhaltigkeitsverordnung. Biokraftstoff-Nachhaltigkeitsverordnung, Bundesanstalt für Landwirtschaft und Ernährung, https://www.ble.de/SharedDocs/Downloads/DE/Klima-Energie/Nachhaltige-Biomasseherstellung/Evaluationsbericht_2016.html.
- [9]. **Jamil Abdo & Tariq Masood “Techno Economics Analysis to Reshape Global Clean and Green Energy” 22nd International Conference on Renewable Energies and Power Quality (ICREPQ’24)** Bilbao (Spain), 26th to 28th June 2024
- [10]. **Tariq Masood & Jamil Abdo “New Technique to Enhance Hybrid Renewable Energy Resources’ Operational Flexibility and Reliability” 22nd International Conference on Renewable Energies and Power Quality (ICREPQ’24)** Bilbao (Spain), 26th to 28th June 2024
- [11]. **Jamil Abdo & Tariq Masood “New Technique to develop Intelligent, highly reliable & Efficient Unmanned Power Generation Modular” 22nd International Conference on Renewable Energies and Power Quality (ICREPQ’24)** Bilbao (Spain), 26th to 28th June 2024
- [12]. **Jamil Abdo & Tariq Masood “Operational Reliability-Production Best Practice Pragmatic Case Studies & Improvement”** published in Proceedings of the 9th North American Conference on Industrial Engineering and Operations Management Washington D.C., USA, June 4-6, 2024.
- [13]. **Tariq Masood & Jamil Abdo “Maintenance strategy production best practices – pragmatic case studies and operations improvement”** published in Proceedings of the 9th North American Conference on Industrial Engineering and Operations Management Washington D.C., USA, June 4-6, 2024
- [14]. **Tariq Masood R. K. Aggarwal and Nasser Al-Emadi “Enhanced Power Flow/Voltage Control in the GCC Grid by SSSC Robustness”** published ISBN: 978-3-659-40995-0. <https://www.morebooks.de/shop-ui/shop/search?q=978-3-659-40995-0&page>
- [15]. **Tariq Masood, DP Kothari “Centralized and Decentralized FACTS Controllers in Electric Power Grid” Subtitle: Innovative Robust Control Applied to Selected Power System** published by New Age International. **ISBN : 978-93-87788-31-2**
- [16]. **Tariq Masood, Muhammad Tajammal, Samer Kareem, Suhail Aftab Qureshi, Abdul Jabbar Khan, DP Kothari, Nair Jameel” Unified power Flow Controller Modeling and Analysis Technique on the GCC Power Grid Operations and Control”** published IEEE Energy Con, 2018 June 7-9 Limassol Cyprus. <https://ieeexplore.ieee.org/document/8398834/>
- [17]. **Tariq Masood, Muhammad Tajammal, Samer Kareem, Suhail Aftab Qureshi, Murtaza Hashmi, Nasir Jameel ”Unified power Flow Controller (UPFC) Modeling and Analysis Technique by using Matlab and EMTF”** published (ICREQP,18 Salamanca Spain 21-23 March,2018). <http://www.icrepq.com/icrepq18/250-18-masood.pdf>
- [18]. **Tariq Masood, Muhammad Tajammal, Samer Kareem, Suhail Aftab Qureshi, Murtaza Hashmi Naser Jameel “STATCOM Controller Performance Enhancement and Optimization Technique”** published (ICREQP,18 Salamanca Spain 21-23 March,18). <http://www.icrepq.com/icrepq18/249-18-masood.pdf>
- [19]. **Dr. Tariq Masood, Dr. Abdel Aty Edris, Dr. Muhammad Tajammal, Dr. Murtaza Hashmi, Dr. Nasser Al-Emadi, Dr. R.K.Aggarwal, Dr. Suhail Aftab Qureshi, Dr. D.P.Kothari “Centralized/Decentralized FACTS Controllers in Electric Grids”** published by New Age International India, UK. <https://www.amazon.in/Centralized-Decentralised-Facts-Controllers-Electric/dp/9387788318>
- [20]. **Tariq Masood, Muhammad Tajammal, Samer Kareem, Suhail Aftab Qureshi, Murtaza Hashmi DP Kothari: “Smart Grid Operational functions and Control Challenges by Implementing SSSC Tailored to Optimize performance in between Qatar and KSA on the GCC Electrical-power grid”** published in the ASTESJ Journal Advances in Science, Technology and Engineering Systems Journal Vol. 2, No. 1, 30.09.2017. <https://pdfs.semanticscholar.org/dfba/184b2f7697d4e1f56d3eae96e4a400d02cd7.pdf>
- [21]. **Tariq Masood, Abdel Aty Edris, Suhail Aftab Qureshi, Muhammad Tajammal, Murtaza Hashmi DP Kothari: Samer Kareem “Smart Grid Operations and Control Challenge by Implementing STATCOM Tailored to Optimization Performance at the GCC Power Grid”** published in the 13th IET International conference on AC and DC power Transmission Conference on 14-16 February, 2017. <http://ieeexplore.ieee.org/document/7934988/>
- [22]. **Tariq Masood, Abdel Aty Edris, Suhail Aftab Qureshi, Muhammad Tajammal, Murtaza Hashmi DP Kothari: Samer Kareem “SSSC tailored to optimization performance in Between United Arab Emirates and Oman on the GCC Power Grid”** published in the 13th IET International conference on AC and DC power Transmission Conference on 14-16 February, 2017. <http://ieeexplore.ieee.org/document/7934934/>
- [23]. **Tariq Masood, R.K. Aggarwal, Nasser Al-Emadi , Suhail Aftab Qureshi, D.P. Kothari “Novel Control of a UPFC Connecting the Kingdom of Saudi Arabia and Kuwait in the GCC Interconnection”,** publication by International Journal of Automation and Power Engineering Volume 3 Issue 1, May 2014. <https://www.academia.edu/34708818>
- [24]. **Tariq Masood, R.K. Aggarwal Nasser Alemadi and D.P. Kothari “Novel Selection Approach of STATCOM Device Tailored and Optimized Engineering Configuration to**

- Implement in Between Qatar and Bahrain': published by International Journal of Automation and Power Engineering Volume 3 Issue 1, March 2014. <https://www.academia.edu/34708817>
- [25]. Tariq Masood, R.K. Aggarwal Nasser Alemadi and D.P. Kothari "Novel Control of a SSSC Connecting the United Arab Emirates and Oman on the GCC Power Grid Interconnection": published by International Journal of Automation and Power Engineering Volume 2 Issue 1, January 2013. <https://www.academia.edu/27492136>
- [26]. Tariq Masood, Abdel Aty-Edris, Rashid A. Alammari R.K. Aggarwal, "Multiple FACTS devices integration through distributed control system and its application on the GCC interconnection" published in 7th IEEE GCC International conference for presentation on 18 November, 2013. <http://ieeexplore.ieee.org/document/6705750/>
- [27]. Tariq Masood, R.K. Aggarwal, Nasser Al-Eamdi "Enhanced Power Flow/Voltage Control in the GCC Grid by SSSC Robustness" published by Lambert in 2013 ISBN: 978-3-659-40995-0. <https://www.amazon.com/Enhanced-Power-Voltage-Control-Robustness/dp/3659409952>
- [28]. Tariq Masood, R.K. Aggarwal, S.A. Qureshi "Novel Control of a SSSC Connecting the Oman and United Arab Emirates in the GCC power Grid Interconnection" published in IJAPE International Journal of Automation and Power Engineering, Volume 2, issue 1 January, 2013. <https://dn790008.ca.archive.org/0/items/IJAPE095/IJAPE095.pdf>
- [29]. Tariq Masood, R.K. Aggarwal, S.A. Qureshi, R.A.J Khan STATCOM and SVC Control Operations and Optimization during Network Fault Conditions: IEEE International Symposium on Industrial Electronics ISIE-2010 Bari Italy (04-07 July, 2010) <http://ieeexplore.ieee.org/document/5636868/>
- [30]. Tariq Masood, R.K. Aggarwal, S.A. Qureshi, R.A.J Khan "STATCOM Model against SVC Control Model Performance Analyses Technique by Matlab": (ICREPQ,10 Granada Spain 23-25 March,10). <http://icrepq.com/icrepq'10/655-Masood.pdf>
- [31]. Tariq Masood, R.K. Aggarwal, S.A. Qureshi, R.A.J Khan "STATCOM Model against SVC Control Model Performance Analyses Technique by Matlab": published in RE & PQJ (Renewable Energy and Power Quality Journal), Vol.1, No.8, April 2010: <https://doi.org/10.24084/repqi08.655> (ISBN: 978-84-613-7543-1)
- [32]. Tariq Masood, R.K. Aggarwal, S.A. Qureshi, R.A.J Khan "STATCOM Control Reconfiguration Technique for Steady State and Dynamic Performance Optimization during Network Fault Conditions": (ICREPQ,10 Granada Spain 23-25 March,10) <http://www.icrepq.com/icrepq'10/656-Masood.pdf>
- [33]. Tariq Masood, R.K. Aggarwal, S.A. Qureshi, R.A.J Khan "STATCOM Control Reconfiguration Technique for Steady State and Dynamic Performance Optimization during Network Fault Conditions": publish in RE & PQJ (Renewable and Power Quality Journal), Vol.1, No.8, April 2010: <https://doi.org/10.24084/repqi08.656> (ISBN: 978-84-613-7543-1)
- [34]. Tariq Masood, Dr. S. A Qureshi, Dr. A.j Khan, Dr.Nasser Elamedi, Yacob Y.Almulla, S K Shah "FACTS Control Devices (STATCOM, SSSC and UPFC) Re-Configuration Techniques By Psim/Matlab" Papers published ICEE2007 on 11-12th April, 2007 at UET/RCET Lahore _ Pakistan. <http://ieeexplore.ieee.org/document/4287295/>