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The accessible large-scale renewable energy potential and its projected influence on Tamil Nadu's grid stability

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ABSTRACT

Due to its inherent geographical potential for wind/solar power and other renewable energy sources (RES) generation, Tamil Nadu is one of the pioneering Indian states in the early development and utilisation of RES. Tamil Nadu accounts for roughly 25% of India's total wind energy capacity. Increased penetration of RES in a power system indicates that RESs have replaced traditional power plants that have historically managed and stabilised the power system, resulting in novel power flow situations. Grid stability must be enhanced in light of the integration of large-scale RES into the grid. The purpose of this research is to analyse and evaluate the impact of large-scale integration of RES by examining mitigating methods from the most recent academic articles and technical reports in this field. This will aid in identifying the key risks affecting the network's stability margin as a result of the widespread integration of RES generation, allowing for a reasonable increase in the network's stability margin. The study's findings will also help to guide the selection of appropriate mitigation strategies. As the stability margin improves, the future fraction of RES additions to the Tamil Nadu extra high voltage (EHV) grid will be increased significantly.

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1. INTRODUCTION

Tamil Nadu transmission corporation limited (TANTRANSCO) is responsible in the state of Tamil Nadu for developing and maintaining a transmission network throughout the state by constructing new substations, transmission lines, and upgrading current systems to meet the state's future demand. TANTRANSCO's transmission network includes a 110 kV level and up to 765 kV grid network [1], connecting all types of generating stations such as thermal, hydel, nuclear, and gas plants, as well as major renewable energy (RE) pooling stations. High penetration of renewable energy sources (RES) in a power system means that RESs have superseded conventional power plants that already have historically controlled and maintained the power system, producing in unique power flow conditions. Because of the incorporation of large-scale RES into the grid, grid stability must be improved.

Tamil Nadu's current generation capacity: the state's average electricity demand is between 15,600 and 16,100 MW. The most varied power generating portfolio in India is Tamil Nadu, with 52% RE, with an installed capacity of 33,695 MW, 44% are coal-fired power plants, 4% are gas-fired power plants, and 4% are long term and medium term open access and captive power plants (CPP) incorporating shares from central generating stations. Figure 1 depicts the current installed capacity of Tamil Nadu's conventional and non-conventional generations as of March 31, 2021 [2] and Figure 2 shows the total RES installed capacity of throughout India as on March 31, 2021. To examine mitigation approaches sourced from the most recent academic publications and technical studies in this sector in order to analyse and assess the impact of large-scale RES integration.

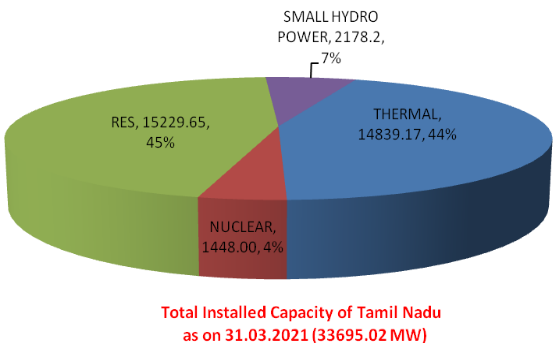

Figure 1. Tamil Nadu's total installed capacity as of March 31, 2021

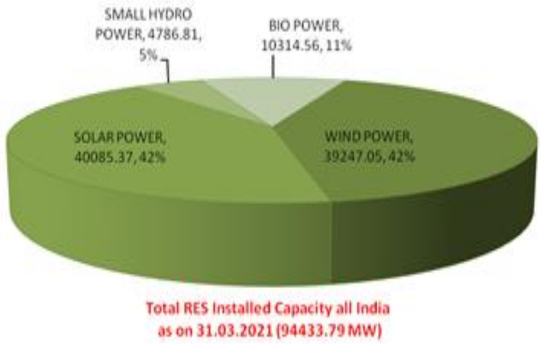

Figure 2. Total installed RES capacity in India as of March 31, 2021

The daily average state consumption has risen from 200 MU in 2011 to 345 MU in 2019, with a maximum consumption of 369.94 MU on April 12, 2019. The largest demand satisfied on 03.04.19 was 16,151 MW [3]. Tamil Nadu is a RE leader, with a total installed capacity of 15,779 MW, secretarial for coarsely half of the state's total installed capacity. The outcomes of the study will also aid in the selection of relevant mitigating techniques. The future proportion of RES contributions to the Tamil Nadu extra high voltage (EHV) grid will develop dramatically as the stability margin increases. The state harnessed 11,717 million units of wind energy and 3,842 million units of solar energy in 2019-2020. The state of Tamil Nadu has a natural wind energy potential, particularly in the key 4 wind passes of Shencottah, Aralvaimozhi, Cumbum and Palghat, which provide essential resources for wind energy generation. Because of the tunneling effect of the South West Monsoon, these primary passes cover the majority of the state's wind potential. The peak wind season in the state lasts from June to September. During this time, 30 to 35% of wind energy capacity was produced in relation to state energy consumption.

The Tamil Nadu government is dedicated to reducing the consequences of climate change in the state by establishing laws that promote RE development. The administration wants RE to become a grassroots movement. The Tamil Nadu energy development agency (TEDA) [4] is a regulations that apply whose mission is to raise awareness and move the state away from the usage of fossil fuels and towards RE. In further paper, demonstrates the Tamil Nadu’s RE potential analysis and literature review in section 2. Proposed solutions are presents in section 3. Finally conclusion part is describes in section 4.

2. ANALYSIS OF THE RE POTENTIAL OF TAMIL NADU

Wind and solar energy are the most abundant RE sources in India. The most RE-rich states include Gujarat, Maharashtra, Tamil Nadu, Andhra Pradesh, and Karnataka. One of the largest large-scale projects was carried out by the Government of India (GOI) with the assistance of United States Agency for International Development (USAID) and the National Renewable Energy Laboratory (NREL). RES integration studies [5] in the year June 2017 and presented the report "Greening the grid: pathways to integrate 175 GW of RE into India's Electric Grid-National Study" which described the following: the Government of India has set a target of 175 GW RE generation capacity by 2022, comprising 60 GW of wind as well as 100 GW of solar. Figure 3 displays India's notional defined contribution (NDC), which expands this objective to 40% non-fossil fuel-based power manufacturing capability by 2030, Figure 3(a) shows 250-300 GW of solar, Figure 3(b) shows wind energy’s capability, Figure 3(c) displays total variable RE output and Figure 3(d) represents load (gigawatt-hours [GWh]) per state, assuming no curtailment and a 100 S-60 W scenario. The Ministry of Electricity has established a variety of projects, including green energy corridors, to assist large-scale RE integration in order to reach these objectives. NREL is able to investigate objectively the possibilities for integrating RE into the power grid in order to increase benefits, increase energy security, and lower costs for the entire nation. Additionally, one of the biggest large-scale RES integration studies was done by TANTRANSCO, Tamil Nadu generation and distribution company Ltd (TANGEDCO), and the United States Department of Energy's NREL [6] and presented the report "Pathways for Tamil Nadu's Electric Power Sector: 2020-2030" on power sector planning, which stated the following.

Tamil Nadu, according to NREL, will be essential to the nation's RE targets. The state has long been a forerunner in wind energy, with wind farms constructed as early as 1995, and now contributes 25% of India's wind generation (ministry of new and renewable energy (MNRE) 2020; TEDA 2020). With a recent governmental aim of constructing 9 GW of solar photovoltaic (PV) by 2023, Tamil Nadu is now prepared to take the lead in solar energy as well (TEDA 2019). Tamil Nadu has expertise implementing vancomycin-resistant enterococci (VRE) into everyday power system operations as an early proponent of both solar and wind power. Cost, and the intersection of technological, cost, and policy variables. The NREL cutting-edge modelling tool enabled the completion of this investigation. The fundamental purpose of this research, as seen in Figure 4, is to identify the best cost-effective choices for Tamil Nadu's electricity supply for the period 2020-2030.

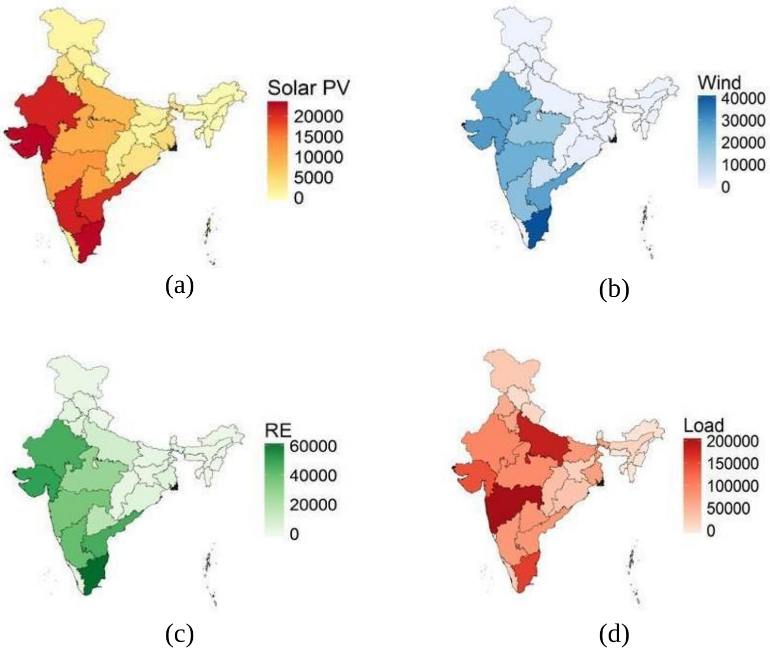

Figure 3. The regional distribution of yearly (a) solar energy, (b) windenergy, (c) total variable RE output, and (d) load (gigawatt-hours [GWh]) per state, assuming no curtailment and a 100 S-60 W scenario, is depicted

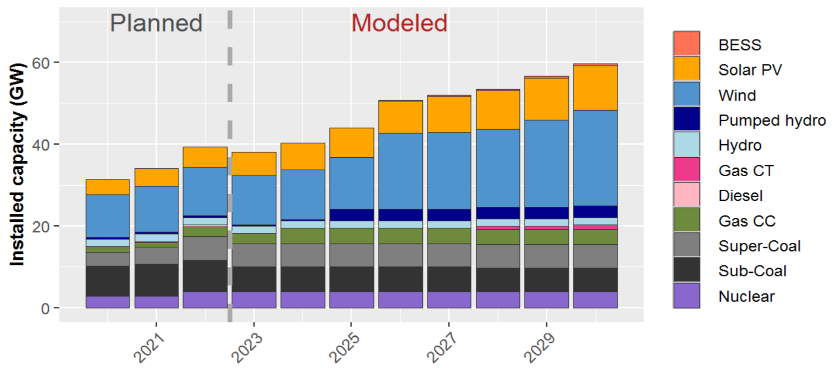

Figure 4. Total electricity generation in the base scenario 2020-2030

This study revealed that Tamil Nadu's electric power system will shortly transition from a thermal-based system to a renewable-based system. According to NREL, wind, solar PV, and battery storage expenditures are becoming more competitive with thermal capacity due to decreased component prices. Battery storage's capacity to move energy from high-RE towards high-load periods, plus with long term capital cost reductions, enables battery energy storage expenditures economically feasible as early as 2025. By showing the temporal and geographical properties of VRE resources in detail, NREL's regional energy deployment system (ReEDS) model specifically tackles concerns with grid integration of VRE technologies. Wind and solar power producing capacity has increased significantly in recent years.

To successfully harvest the enormous potential of wind and solar power, the MNRE [7] has already begun the implementation of dedicated interstate and intrastate pathways Schemes under the Green Energy Corridor project in collaboration with TANTRANSCO. These routes will aid in transferring the enormous potential of wind and solar power to load demand areas. In the interest of effectively executing the project, power grid corporation of India Ltd, Gurgaon produced an in-depth research report [8] in regards of "Survey on Green Energy Corridor" in order to determine the infrastructure facilities and other maintaining compliance for RE maximize the performance programme as part of 12th plan period [9], and recorded the following:

– During the 12th Plan era, determining the transmission infrastructure needed to accommodate prospective increases in RE -based electricity (wind, solar, and hydro) in the renewable-rich states of Tamil Nadu, Karnataka, Andhra Pradesh, Gujarat, Maharashtra, Rajasthan, and Himachal Pradesh.
– Renewable capacity expansion in the 12th Plan is anticipated to be roughly 41,500 MW, based on information obtained from respective SNA/STU (30,400 MW wind, 9400 MW solar and Small Hydro 1700 MW). Table 1 illustrates the renewable capacity augmentation programmes by state.

Table 1. Wind/solar addition plan for RE rich states

State	Existing Capacity (MW)		Addition in 12th Plan (MW)		Total capacity (MW)	
	Wind	Solar	Wind	Solar	Wind	Solar
Tamil Nadu	6,370	7	6,000	3,000	12,370	3,007
Karnataka	1,783	6	3,223	160	5,006	166
A.P	392	92	5,048	285	5,440	377
Gujarat	2,600	600	5,083	1,400	7,683	2,000
Maharashtra	2,460	17	9,016	905	11,476	922
Rajasthan	2,100	200	2,000	3,700	4,100	3,900
Total	15,755	922	30,370	9,450	46,075	10,372

In 2015-2016, the Ministry authorised the intra state transmission system (InSTS) project for large-scale RE evacuation [10]. It is being implemented in eight states where renewable resources are abundant: Rajasthan, Tamil Nadu, Andhra Pradesh, Karnataka, Gujarat, Maharashtra, and Madhya Pradeshand Himachal Pradesh. The initiative is being carried out by the states' respective state transmission utilities (STUs). The project will contain roughly 9,400 circuit kilometres of transmission network and substations with an overall capacity of 19,000 MVA when finished in March 2020. 20,000 MW of large-scale renewable power will be evacuated, and participating states' grid infrastructure will be updated. Apart from the above identification of the predominant potential of RES generations, In March 2018 [11], the global wind energy council (GWEC), which in itself is implementing the intermediary offshore wind in India (FOWIND) project in India, presented a research report titled "Feasibility Study for Offshore Wind Farm Development In Tamil Nadu," which is mainly focused on Tamil Nadu's promising offshore wind development area. This research built on their prior published work, which includes a Pre-feasibility Study in 2015 [12], a logistics study in 2016, and a grid integration study in 2017. The following events occurred, according to the full analysis:

The purpose of this project is to provide a concept design for a demonstration project ranging from 150 MW to 504 MW located in one of Tamil Nadu's highest prospective offshore wind development sites [13]. FOWIND was confident that this study would serve as a springboard for companies and government agencies to conducteven farther extensive offshore front end engineering design (FEED) investigations, and assisting in the identification of critical project hazards in Tamil Nadu, would benefit from this research [14]. In this article, FOWIND found various viable technological options for offshore wind production by modelling available public domain data. The paper included high-level preliminary research on project siting, wind farm design, and implementation methodologies. The RISAT-1 SAR-derived offshore wind speed heat map of Tamil Nadu is depicted in Figure 5 [15].

In this study, various types of wind turbines with ride-through functionality were examined in relation to the Indian grid code [16], [17]. These results of stability studies recommended the possibility of accommodation of maximum wind generation of 29.3% without loss of stability from previous 26.8% by comparing stability cases of operating scenario studied and increased operating scenario are given in Table 2. Further, the authors calculated the reserve margin requirement for the TANGEDCO system for the operating scenario of 26.81% wind penetration to be between 553 MW and 605 MW and the increased operating scenario of 29.29% wind penetration to be between 579 MW and 749 MW, and they advised that a reserve margin of approximately 4.7% be maintained to achieve 30% wind penetration [18], [19]. This study thoroughly examined the stability of the current system in the event of a sudden cessation of wind generation and made recommendations for the necessary variables to enhance wind penetration levels in the TANGEDCO system for stable operation of the power system network. This detailed work suggested the requirement of additional reactive power compensation and the requirement of generation reserve margins to attain maximum wind penetration in the existing system.

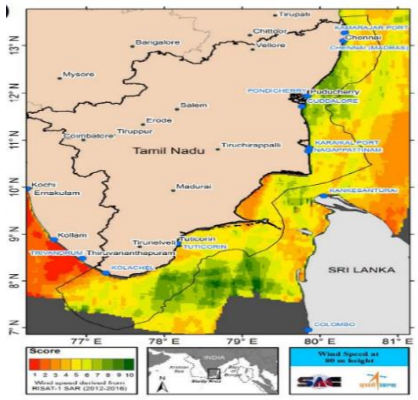

Figure 5. Tamil Nadu RISAT-1 SAR offshore wind speed heat map

Table 2. Summary of stability results

Scenarios	Operating scenario studied	Increased wind operating scenario studied
Generation of wind	4,005 MW	4,586 MW
Peak load	14,947 MW	15,652 MW
Wind capacity penetration	26.8%	29.3%
Sudden loss of wind in Udumalpet	Stable–for loss of 12.6%	Stable–for loss of 13.45%
Sudden loss of wind in Tirunelveli	Stable–for loss of 14.2%	Unstable–for loss of 13.41%
Sudden loss of wind Udumalpet and Tirunelveli	Unstable–or more than 16.71% loss	Unstable–for more than 15.95% loss

2.1. Wind energy potential in selected locations with unknown factors: a techno-economic study [20]

This research effort primarily concentrated on assessing the techno-economical benefit of wind energy potential attainable in the primary four wind passages of Aralvaimozhi, Shencottah, Palghat, and Cumbum in order to appreciate the nature of wind flow and its potential in the Tamil Nadu area [21], [22]. In this research study, authors had taken twenty years of (from the year 2000 to 2019) time-series data of historical, wind speed and direction data of 4 wind passes. This study received funding from admin by the the Ministry of Education's Basic Science Research Program, National Research Foundation of Korea [23], [24] (NRF) as well as assistance from the Korea Electric Power Corporation with the help of historical time-series data, they had first evaluated the potential wind in the Aralvaimozhi, Shencottah, Palghat, and Cumbum regions. They next calculated the Weibull parameters-c (scale) and k (shape), using the MEERA data set, as shown in Figures 6 and 7.

Researchers used these data to calculate most likely speed, the mean speed, power density, and maximum electricity speed of wind power during each of the four wind passes. The analysis found that all four crossings had superior wind characteristics [25]. The scientists also established the likelihood of exceedance, wake loss impact (WLE), surface roughness and wind shear coefficient (WSC). This study carefully examined the wind potential of the four main wind passes in Tamil Nadu, finding that the Aralvaimozhi pass has a much greater potential than the other four. It has a better range of mean wind speeds of about 6.563 m/s, wind power densities of about 226 w/m^2, most probable wind speeds of about 6,403 m/s, and maximum wind speeds of about 8,699 m/s and further recommended that the aralvaimozhi wind pass location will be better suited for adding more wind turbines in order to generate significant amounts of green energy [26]. The wind speed characteristics of the aforementioned wind passes in Tamil Nadu, India, at a hub height of 50 metres shown in Table 3.

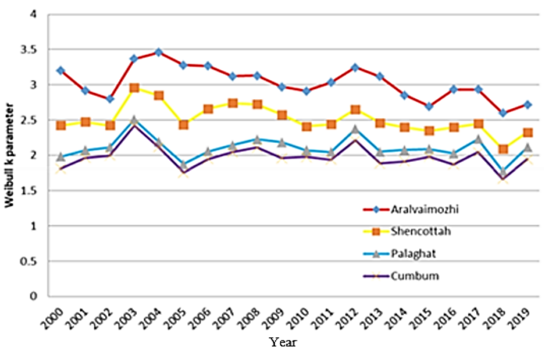

Figure 6. Weibull shape parameter—k

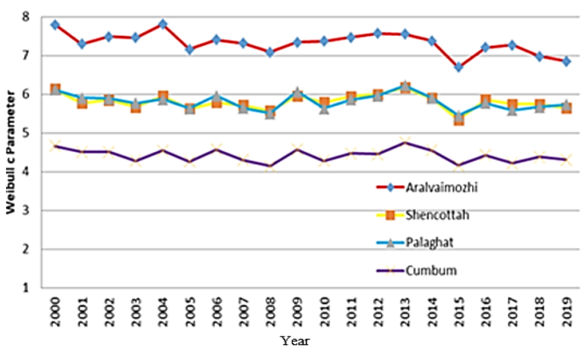

Figure 7. Weibull scale parameter—c

Table 3. Wind turbine characteristics of wind flows in Tamil Nadu, India, at a hub height of 50 metres

Wind Pass	Wei-bullk (Dimensionless)	Wei-bullc (m/s)	Mean wind speed (m/s)	Wind power density (W/m2)	Most probable wind speed (m/s)	Max. wind speed (m/s)
Palghat	2.08	5.84	5.146	142	4.249	8.025
Cumbum	1.93	4.41	3.912	66	3.056	6.352
Shencottah	2.48	5.78	5.164	122	4.718	7.380
Aralvaimozhi	2.95	7.27	6.563	226	6.403	8.699

3. PROPOSED SOLUTION

It is evident from the works that were conducted as part of the literature survey that the authors have conducted in-depth research and analysis of the key effects that have been observed on the power system. These implications include geographic variety of variable resources, renewable forecasting, generator flexibility, energy storage, and wind and solar power curtailment owing to large-scale RE integration. Authors have proposed workable solutions, controls, and ways to mitigation based on the findings of their study in order to cope with the integration challenges and achieve the largest potential exploitation of RE sources inside the traditional grid. According to the primary research findings collected from NREL and power grid corporation of india limited (PGCIL), it is crystal clear that the state of Tamil Nadu contributes a big energy potential for the development of wind and solar electricity in comparison to other states. In comparison to other SEBs, Tamil Nadu's wind farms were among the first to be built. Today, the state is responsible for close to 25% of India's total wind capacity and it also possesses a preponderance of solar energy resources.

The most important problem that Tamil Nadu needs to solve right now is figuring out how to run the grid in a safe and secure manner, particularly in light of the impending large-scale increase in the capacity of RES that was discussed in this study. This is the primary challenge that the state is facing right now. This requires meticulous planning of the power system and the construction of the network, in addition to tried-and-true control methods, in order to provide a more seamless operation. This suggests that there is room for further research into the impact of large-scale RES integration into the main grid as well as the need for a more thorough investigation into the best mitigation strategy for the secure operation of the transmission system in the state of Tamil Nadu. In light of the fact that the future would require the aforementioned things, the author has recommended putting a self-regulated mechanism within the existing network, which would consist of FACTS devices like static synchronous compensator (STATCOM) with a suitable control algorithm in the existing EHV networkas presented in Figure 8. These self-decisive FACTS devices will monitor the behaviour of the system in real time based onlocal data in order to make judgments regarding power flow. The proposed methodology has the potential to tweak the network parameters and stabilises the existing system based on appropriate control actions. In this work, the new contributions are FACTS controller like STATCOM, solar/wind pooling station with proposed communication interface system, whereas, the FACTS devices is controlled by remote devices.

In order to manage current flow and improve transient stability on power grids, power electronic devices are employed in the STATCOM, a shunt device belonging to the FACTS family. The STATCOM controls the amount of reactive power added to or subtracted from the electrical grid in order to maintain a constant terminal voltage. The STATCOM creates reactive power whenever the system voltage is low (in capacitive mode), and it consumes reactive power when the system voltage is high (inductive mode). As seen in Figure 9, source V1 indicates the STATCOM's output voltage. When the reactive power demand in the power system grows, STATCOM improves its output voltage V1 while keeping the phase difference between V1 and V2 at zero.

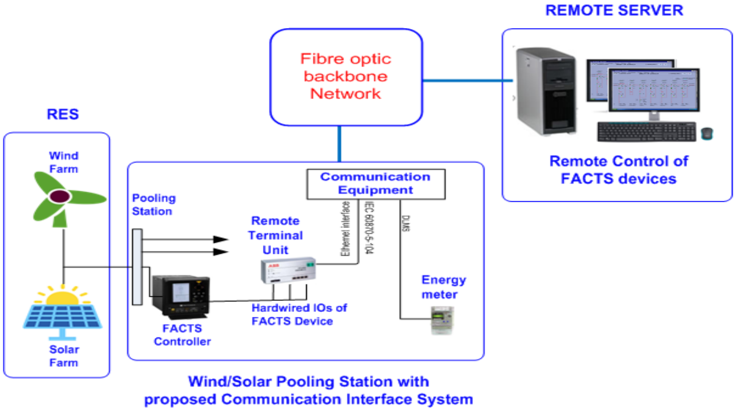

Figure 8. Demonstrates the proposed coordinated power control, which makes use of self-regulated FACTS devices, derived from local system data

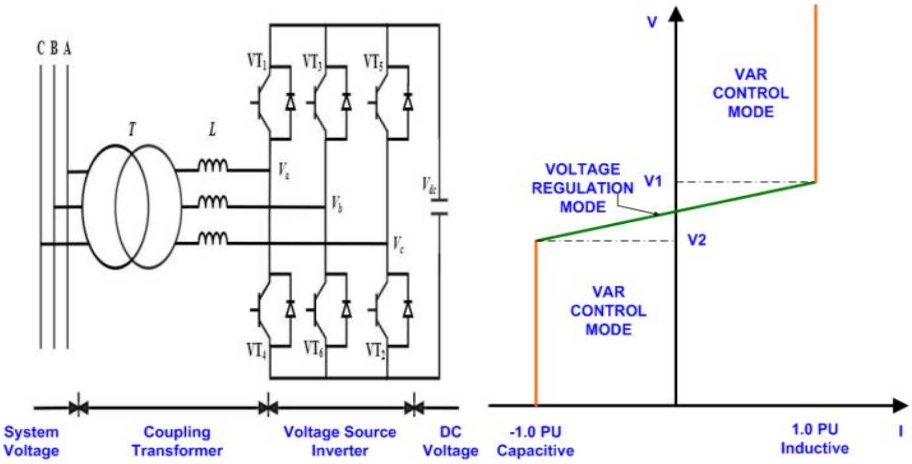

Figure 9. Basic structure of STATCOM and it's V-I characteristics

Reactive power will be transmitted from STATCOM to the power system as V1>V2. Hence, STATCOM provides reactive power and serves as a reactive power generator. The author is confident that implementing the proposed strategy along with coordinated control of FACTS devices will greatly improve the stability margin of the current Tamil Nadu EHV network, which has the highest proportion of wind and other RES generation.

4. CONCLUSION

Author observed that with the proposed mitigation technique, future research on the EHV Transmission system in the state of Tamil Nadu can be undertaken in depth, and current and future operating scenarios can be investigated. Adopting appropriate monitoring and control methods as well as mitigating strategies to accommodate the variable nature of large-scale RES generation for grid integration in light of the imminent installation of massive RES capacity. In addition, future research may address the primary risks that are altering the stability margin of the Tamil Nadu EHV network as a result of the large integration of RES, and the results of such research must contribute to a sensible rise in the grid's stability margin. Due to the improvement in the entire grid stability margin, the proportion of RES that can be added to the EHV grid in the foreseeable future can be efficiently increased. This research work evaluates the significant RE potential in the Indian state of Tamil Nadu, based on a variety of recently conducted studies in the state. Author strongly advises that the installation of a self-regulated FACTS mechanism with an appropriate control algorithm into the current EHV network will monitor the local system data, resulting in a sensible increase in stability margin of EHV grid.

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