Enhancement of Power Transient Stability via F_NIDC optimized STATCOM with Integrated Energy Storage Model

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Abstract: - In Interconnected power system, it must maintain power, voltage, and frequency quality within specified limits. Because of low frequency oscillations are inherently present in power systems as a result of disturbances; extreme caution is required to maintain their stability. FACTS devices are used to improve power system stability using the proposed F_NIDC method. This work establishes an Optimized STATCOM via Efficacious Energy Storage Model in order to stabilize the power system. F_NIDC is a hybrid of a Fuzzy logic controller and a Novel Intelligent Damping Controller (NIDC) that is used to achieve a rapid improvement in transient stability and fault clearing time. Battery storage is used in conjunction with a super capacitor as an energy storage scheme (ESS). It is linked to a STATCOM in order to stabilize and mitigate system oscillations. STATCOM must be fine-tuned using the Consortium Time-Domain based Optimization Algorithm, which has a high ability to find the most relevant and optimistic outcomes. As a result, a novel F_NIDC design is proposed in this paper to implement such a system.

Keywords: - Flexible alternating current transmission system (FACTS), Static Synchronous Compensator (STATCOM), Novel Intelligent Damping Controller, Fuzzy Logic Controller.

Received: March 11, 2022. Revised: September 9, 2022. Accepted: October 12, 2022. Published: November 2, 2022.

Nomenclature:-

$\mathbf{I}_{statcom}$	-	STATCOM current
I	-	Injected Current
V	-	Injected Current
$\mathbf{V}_w$	-	Voltage magnitude
$\boldsymbol{\delta}$	-	Internal angle
$\boldsymbol{\delta}_w$	-	STATCOM bus angle
E'	-	Internal voltage
E	-	Infinite bus voltage
P_{load}	-	Load power

1 Introduction

Operation and control in modern power systems become more challenging day-by-day because of the integration of renewable energy resources, interfacing of different converters and deregulation. The power system is basically composed of generation, transmission and distribution systems where thermal, hydro and nuclear-based conventional power plants are being integrated with renewable energy resources such as solar, wind, biomass and so on to meet the power demand [1]. The interconnected power system must maintain the quality of power, voltage, frequency so that they will be within the specified limits [2]. However, System stability is threatened due to the occurrence of various disturbances, islanding, any abnormal condition and sudden variation in loads. Stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance. Transient stability analysis is considered when the power system is confronted with large disturbances [3]. Sudden changes in load, generation or transmission system configuration due to fault or switching are examples of large disturbances. Power system should retain its synchronism during and after all these kinds of disturbances. Therefore transient stability is an important security criterion in power systems design. Different methods have been used for transient stability analysis in power systems [4].

Low frequency oscillations are inherently present in power systems because of the above-mentioned events and hence utmost care is needed in order to maintain their stability [5]. In order to provide a significant damping torque, power system stabilizers (PSS) have been traditionally employed for effective excitation control [6]. PSS supplies additional stabilizing signals in phase with the rotor oscillations to the AVR circuit to improve the voltage profile. But, the efficiency of this conventional PSS is observed to be degraded in the event of severe disturbances. Extensive research has been carried out by many researchers to design an optimal PSS based on soft computing techniques. Further, Fast acting converter-based devices called Flexible AC Transmission Systems (FACTS) are becoming popular to achieve a better active and reactive power management which enhances the transient as well as dynamic stability. FACTS devices respond quickly to disturbances and employ necessary control measures so that the system parameters stay within their specified limits. Among them, SVC is a shunt type FACTS controller [7] whose performance and efficiency can be enhanced by tuning its parameters using soft computing approaches like artificial neural network (ANN), genetic algorithm (GA), firefly algorithm (FA), particle swarm optimization (PSO), bacteria foraging optimization algorithm (BFO), flower pollination (FP) etc. [8]

Among the FACTS devices, the Static Synchronous Compensator (STATCOM) is of particular interest in this study because this device is able to improve the transfer capability of a power system by improving voltage regulation and stability and can significantly provide smooth and rapid reactive power compensation for voltage support and for enhancing both damping of power oscillations and transient stability. This device has been applied both at distribution level to mitigate power quality phenomena and at transmission level for voltage control and power oscillation damping (POD).

Energy storage has been discussed as an important technology for addressing the intermittency of renewable resources as well as providing a means for load leveling [9]. However, energy storage can also play an important role in the real-time control of real and reactive power, thereby enhancing both small- and large-signal stability and security of the power system. Of particular interest is the use of energy storage not only to improve transient stability and damping of power oscillations but also to increase power transfer capability of power systems. By equipping the STATCOM with an energy storage connected to the dc-link of the converter, a more flexible control of the transmission system can be achieved. Low-frequency electromechanical oscillations are common in the power system and are a cause for concern regarding secure system operation, especially in a weak transmission system [10]. In this regard, FACTS controllers, both in shunt and series configuration, have been widely used to enhance stability of the power system [11].

In the specific case of shunt connected FACTS controllers, first swing stability and POD can be achieved by modulating the voltage at the point of common coupling (PCC) using reactive power injection [12]. However, one drawback of the shunt configuration for this kind of applications is that the PCC voltage must be regulated within specific limits, and this reduces the amount of damping that can be provided by the compensator [13]. Moreover, the amount of injected reactive power needed to modulate the PCC voltage depends on the short circuit impedance of the grid seen at the connection point. Injection of active power, on the other hand, affects the PCC-voltage angle without varying the voltage magnitude significantly. [14]

Thus in a power system, stabilizing the transient stability problem and mitigating the damping system oscillations are crucial for the secure operation of today's heavily loaded power systems. Hence to implement such type of system, a novel design is proposed in this work.

2 Literature Survey

[15] presented a robust Partial Differential Equation-based (PDE) control strategy, which had optimally control both distributed energy storage systems and photovoltaic power plants to enhance the stability margins of synchronous generators. The presented nonlinear controller was robust to unknown time-varying delay and uncertainties on measurements. A time delay compensation technique was developed to inject delay-free control signal into the closed-loop system.

[16] Developed a new nonlinear control approach to coordinate doubly fed induction generator (DFIG)-based wind turbines and static synchronous compensator (STATCOM) controllers in multi-machine power systems. Its main objective was to improve the transient and voltage stability of the inter-connected multi-machine power system via

simultaneous design of the voltage of the DFIGs' rotors and reference current of STATCOM. The nonlinear approach has reduced the effects of the linearization error.

[17] Employed an auxiliary (supplementary) controller for static synchronous compensator (STATCOM) to improve the transient stability limit of multi machine power systems. The developed control method is successfully applied to the New England 10-machine, 39-bus test system. The STATCOM controller via a trial-and-error approach and performing several time-domain simulations were very time-consuming. To speed up the method of calculating that gain in online applications, a multilayered perceptron (MLP) neural network (NN)-based approach is proposed in this paper.

[18] Investigated the enactment of battery energy storage system (BESS) and static compensator (STATCOM) in enhancing large-scale power system transient voltage and frequency stability, and improving power export capacity within two interconnected power systems. A PI-lead and lead-lag controlled BESS was proposed for multi-machine power system to provide simultaneous voltage and frequency regulation within the defined battery state-of-charge ranges and an equivalent Finnish transmission grid is used to evaluate the system performance.

[19] Applied an intelligent damping controller (NIDC) for the static synchronous compensator (STATCOM) to reduce the power fluctuations, voltage support and damping in a hybrid power multi-system. It has integrated the offshore wind farm (OWF) and a seashore wave power farm (SWPF) via a high-voltage, alternating current (HVAC) electric power transmission line that connects the STATCOM and the 12-bus hybrid power multi-system. The hybrid multi-system consisted of a battery energy storage system (BESS) and a micro-turbine generation (MTG) to achieve better damping characteristics and effectively stabilize the network under unstable conditions.

[20] Siemens in Germany is working on a number of fuzzy control applications. These classifications are also explained using examples such as optimization theory, fuzzy data analysis, and fuzzy expert systems, among others. Different fuzzy controller optimization techniques, such as generic algorithms (GA) and Rosenbrok's algorithms, are also discussed. In addition, the multilevel qualitative optimization.

With the rapid increase of the size and complexity of power systems, power system stability and performance are of increasing importance in the operation of power systems. Recently, power system operation is faced with the difficult task of maintaining transient stability when a diversity of disturbances unavoidably occurs in the power system. The interconnected power system must maintain the quality of power, voltage, frequency so that they will be within the specified limits. In addition, the complexities in power system creates unpredicted load switching operations and faults, power system variables undergo small or large oscillations, which also leads to stability issues. Prior works fails to regulate PCC voltage within specific limits, and this reduces the amount of damping that can be provided by the compensator; which would create system oscillations. The disturbances in load that are caused in the power system degrade the fault clearing time, which would simultaneously affect the system performance. Thus, getting motivated from the aforementioned issue, a novel and effective design is to be modelled in our proposed work.

However all those methodologies works well, they got affected with some performance metrics like reduced fault clearing time due to their complex structures, which leads to high system complexities. To deal with such situations, a novelty is required in the field of power system with efficient energy storage scheme; thereby initiates a way to enhance transient stability.

3 Enhancement of Power Transient Stability

This paper proposes an Optimized STATCOM via Efficacious Energy Storage Model to stabilise the power system. A battery storage system is used in conjunction with a super capacitor as an energy storage scheme (ESS) for stabilizing and mitigating the system oscillation of energy storage. The proposed F NIDC is used to achieve a rapid increase in transient stability and fault clearing time. It effectively mitigates a wide range of power system disturbances that are unavoidable. To do so, the STATCOM power controller parameters must be fine-tuned using the Consortium Time-Domain based Optimization Algorithm, which has a strong ability to find the most relevant and optimistic outcomes. As a result, the proposed work effectively mitigates system damping oscillations with utmost transient stability by averting all those disturbances that occur in power systems using optimised parameters, which improves fault clearing time at the same time. The upcoming section explains F_NIDC optimized STATCOM Model to stabilise the power system.

Figure 1: Proposed Power System Model

3.1 F_NIDC optimized STATCOM

In this method, F_NIDC is deployed here to achieve an abrupt progress in the transient stability along with fault clearing time. PV panel is connected to the DC link of the converter. Next the voltage and current will be measured by using voltage sensor and current sensor. Subsequently, DC link is connected to induce the current and it flows through the load side. Here Fuzzy Logic controller is used to mitigate Power system Oscillation linked to the STATCOM. Moreover MPPT, PNO controller is connected between the battery and Super capacitor for energy storing purpose. Maximum Power Point Tracker (MPPT) System Perturbation and Observation (PNO) controller used to achieve the operating point (OP) of a photovoltaic generator system (PGS) should be adjusted the highest solar cell efficiency. Thus the proposed system maintains its stability and efficient energy storage scheme which is shown in figure 2.

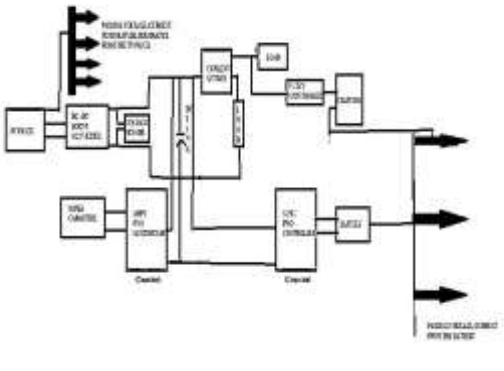

Figure 2: Block Diagram of the Proposed Method

A static synchronous compensator (STATCOM) also called as a static synchronous condenser (STATCON). It is a regulating device used on AC transmission networks. It is based on a voltage-source converter in power electronics and can be used as a source or sink of reactive AC power in an electrical network. It can also provide active AC power when connected to a power source. Voltage fluctuations can also be reduced using these compensators. It’s a part of the FACTS family of devices. It's designed to be modular and electable.

A voltage source converter (VSC)-based system with the voltage source behind a reactor is known as a STATCOM. It has the voltage source is a DC capacitor, so the STATCOM has a very low active power capability. However, if a suitable energy storage unit is connected across the DC capacitor, its active power capacity may be increased. The amplitude of the voltage source determines the reactive power at the STATCOM terminals. As an example, The STATCOM produces reactive current when the VSC's terminal voltage is higher than the AC voltage at the point of connection; conversely, when the voltage source's amplitude is lower than the AC voltage, it absorbs reactive power. Because of the fast-switching times offered by the voltage source converter's IGBT, the response time of a STATCOM is faster than that of an SVC. In this project, using super capacitor and a Battery is a voltage source for energy management for improving transient stability.

The most active research field in the application of fuzzy set theory, fuzzy reasoning, and fuzzy logic is fuzzy logic control (FLC). FLC is used in a variety of applications, including industrial process control, biomedical instrumentation, and security.FLC has performed better in complex ill-defined problems that can be controlled by an effective human operator without knowledge of the underlying dynamics, as compared to traditional control techniques. A control device is a collection of physical components that are used to change the behavior of another physical system so that it exhibits those desired characteristics. Open-loop and closed-loop control systems are the two types of control systems. The input control action in open-loop control systems is independent of the physical device performance. In a closed-loop control system, the input control operation is determined by the physical system output. Closed-loop control systems, also known as feedback control systems. Every physical variable must first be measured before it can be regulated. The monitored signal is measured by a sensor. A plant is a controlled physical system. The forcing signals of the system inputs are calculated by the system output responses in a closed-loop control system. The fuzzy control rules are IF-THEN rules in disguise.

The steps for designing a controller for a complex physical system are as follows:

1. The large-scale machine is broken down into a number of subsystems.

2. Slowly changing plant dynamics and linearizing nonlinear plane dynamics around a number of operating points.

3. For the system under consideration, organizing a collection of state variables, control variables, or output features.

4. For the subsystems, designing basic P, PD, and PID controllers. It is also possible to construct optimal controllers.

There may be uncertainties in the measures after the first four steps, due to external environmental conditions. The controller design should be as close as possible to the optimum controller design based on the control engineer's professional knowledge. Finally, a supervisory control system, either manual or automatic, creates an additional feedback control loop to tune and modify the controller's parameters to compensate for nonlinear and remodeled dynamics' variation effects. In comparison to a traditional control system design, if an FLC system is chosen, the following assumptions should be made. The plant should be observable and controllable under consideration. There should be a wide range of information available, including expert linguistic rules, basic engineering common sense, a collection of data for input/output, or a controller analytic model that can be fuzzified and from which the fuzzy rule can be created. Also, a solution should exist for the problem under consideration, and it should be such that the control engineer is working toward a "fine" solution rather than an optimal solution. In this case, the controller should be built to the best of our abilities while remaining within a reasonable precision range. It should be noted that in the design of fuzzy controllers, problems of stability and optimality persist.

The process of designing fuzzy rules is critical in the design of a fuzzy logic controller. The fuzzy production rule system has four structures, as defined by Weiss and Donnel (1979):

1. A number of rules that reflects the expert decision- maker's policies and heuristic strategies.

2. A compilation of input data that is analyzed right before a decision is made.

3. When data is available, a method for assessing any proposed action in terms of its conformity to the expressed rules.

4. A method for coming up with promising acts and identifying when to stop searching for better ones.

Membership functions specify all of the required parameters for the fuzzy logic controller. Approximate reasoning and interpolative reasoning methods are used to evaluate the rules. These four fuzzy rule structures help in the development of a control surface that connects the control behavior to the measured state or output variable. The control surface can then be sampled down to a finite number of points, and a lookup table can be built using this data. The knowledge about the control surface is stored in the lookup table, which can be downloaded into a read-only memory chip. FLC System Architecture and Operations are shown below:

Figure 3 depicts the basic architecture of a fuzzy logic controller. A fuzzifier, a fuzzy rule base, a fuzzy knowledge base, an inference engine, and a defuzzifier are the main components of an FLC system. It also includes normalization parameters.

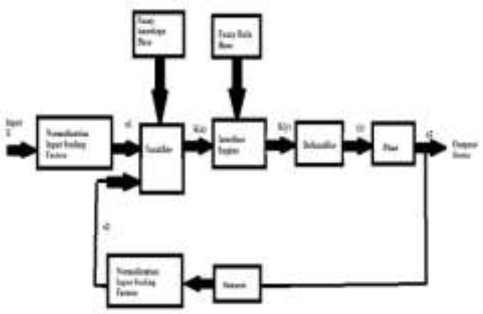

Figure 3. Basic architecture of the System

The following are the steps involved in designing a F_NIDC:

Step 1: Find the input, output, and state variables for the plane under consideration.

Step 2: Divide each variable's entire universe of discourse into a number of fuzzy subsets, assigning each with a linguistic label. All of the elements in the universe are included in the subsets.

Step 3: For each fuzzy subset, obtain the membership function.

Step 4: Form the rule base by assigning fuzzy relationships between the inputs or states of fuzzy subsets on one side and the outputs of fuzzy subsets on the other.

Step 5: For normalizing the variables between the [0, 1] and [-1, I] intervals, choose appropriate scaling factors for the input and output variables.

Step 6: Accomplish the fuzzification process.

Step 7: Using fuzzy approximate reasoning, determine the output contributed by each rule.

Step 8: Combine the fuzzily generated outputs from each rule.

Step 9: Finally, defuzzify the output to create a crisp result.

For a simple FLC system, the steps listed above are performed and executed. For the purpose of designing a general FLC system, the following design elements are used:

1. Fuzzification strategies and a fuzzifier's interpretation
2. Fuzzy knowledge base: Normalization of the parameters involved, partitioning of the input and output spaces, and selection of membership functions for a primary fuzzy set are all part of the fuzzy knowledge base.
3. Fuzzy rule base: Selection of input and output variables; source of fuzzy control rules; types of fuzzy control rules; and completeness of fuzzy control rules.
4. Decision· making logic: The proper definition of fuzzy implication; connective "and" interpretation; connective "or" interpretation; inference engine.
5. Defuzzification materials and a defuzzifier's interpretation.

FLC systems are used in a wide variety of industrial and commercial products and systems. FLC systems have proven to be very efficient in comparison to other conventional control systems in a variety of applications involving nonlinear, time-varying, ill-defined, and complex systems. The applications of FLC system are Traffic Control, Steam Engine, Aircraft Flight Control, Missile Control, Adaptive Control, Liquid-Level Control, Helicopter Model, Boiler Control, Nuclear Reactor Control, Power Systems Control, Air Conditioner Control (Temperature Controller), and Biological Processes, Knowledge-Based System, Fault Detection Control Unit, Fuzzy Hardware implementation and Fuzzy Computers etc…

Smart grids and micro grids have become popular topics for energy demand in recent years. Themicro grid allows for the effective integration of various distributed generation (DG) sources, particularly renewable energy sources, and thus the reduction of CO2 emissions. To maintain a good quality of power supply, a systematic study with an effective solution approach is required. Much of the literature suggested using state feedback control techniques or other linear damping controllers for the STATCOM to improve the damping of power oscillations. External controllers using intelligent control schemes, such as fuzzy logic controllers, neuro-fuzzy external controllers, hybrid controllers, and a Gray-Based Genetic algorithm, have been proposed in some studies. To damping power system oscillations, this paper proposed a novel intelligent damping controller (NIDC) for the STATCOM. The proposed F_NIDC consists of NIDC and Fuzzy Logic Controller using Consortium Time domain-based algorithm. The STATCOM's NIDC is designed to improve transient stability as well as system oscillations. Conventional controllers' performance degrades in such an environment, and it must be reset to maintain the desired performance, a flaw that the proposed approach can overcome. The adaptive critic network is compared to the Fuzzy logic controller using consortium time domain-based algorithm so that the output signal can be used to correct the designed controller and produce the optimal damping control signal of STATCOM for energy storage management. The NIDC is unlike traditional controllers, whose performance degrades as a result of such changes and necessitates retuning to achieve the desired result. The main contribution of this paper is the discovery that energy storage management, a robust NIDC connected to the STATCOM can effectively mitigate power oscillations. In the proposed F_NIDC method deployed efficiently improved the stability of the system. The upcoming section explains Efficacious Energy Storage Model for energy storage management for stabilizing and mitigating the system oscillation.

3. 2. Efficacious Energy Storage Model

In Efficacious Energy Storage Model, a super capacitor is used in conjunction with a battery storage system to act as an energy storage system (ESS) for energy storage. It is linked to a STATCOM in order to stabilize and mitigate system oscillations. Energy storage is the process of capturing energy generated at one time and storing it for later use in order to minimize energy demand-supply imbalances. An accumulator, also known as a battery, is a device that stores energy. Radiation, chemical, gravitational potential, electrical potential, electricity, elevated temperature, latent heat, and kinetic energy are all examples of energy. Energy storage entails transferring energy from difficult-to-store forms to more convenient forms. Some technologies contribute short-term energy storage while others can provide for much longer. Grid energy storage refers to a collection of techniques for storing energy on a wide scale inside a power grid. Super capacitor and Battery is used here for energy storage management.

A super capacitor (SC), also known as an ultra-capacitor, is a high-capacity capacitor that bridges the gap between electrolytic capacitors and rechargeable batteries by having a capacitance value much higher than other capacitors but lower voltage limits. It can hold 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, accepts and delivers charge much faster than batteries, and can withstand far more charge and discharge cycles than rechargeable batteries. In cars, buses, trains, cranes, and elevators, super capacitors are used for regenerative braking, short-term energy storage, or burst-mode power delivery, rather than long-term compact energy storage. For static random-access memory, smaller units are used as a power backup (SRAM). Here, Energy storage has been addressed as an effective technology for resolving renewable resource intermittency and providing a load leveling mechanism. On the other hand, it can help with real-time regulation of real and reactive power, improving the power system's small- and large-signal stability and security. The use of energy storage is to boost transient stability and damping of power oscillations, as well as to increase power transfer capacity of power systems, is of particular interest. A more flexible control of the transmission system can be accomplished by equipping the STATCOM using Super capacitor with an energy storage connected to the converter's dc-link.

In contrast to main battery, this is supplied fully charged and discarded after use. A rechargeable battery, storage battery, or secondary cell (or archaically accumulator) is a form of electrical battery that can be charged, discharged into a load, and recharged several times. One or more electrochemical cells make up this unit. Since it accumulates and stores energy through a reversible electrochemical reaction, the term "accumulator" is used. From button cells to megawatt systems connected to stabilize an electrical distribution network, rechargeable batteries come in a variety of shapes and sizes. Several different combinations of electrode materials and electrolytes are used, including lead–acid, zinc-air, nickel–cadmium (NiCd), nickel–metal hydride (NiMH), lithium-ion(Li-ion), Lithium Iron Phosphate (LiFePO4), and lithium-ion polymer (Li-ion polymer). Automobile starters, portable consumer devices, light vehicle tools, uninterruptible power supplies, and energy storage power stations are all devices that use rechargeable batteries. The technology is being driven by emerging applications of hybrid internal combustion-battery and electric vehicles, which are reducing cost, weight, and size while increasing lifespan. Some newer low self-discharge NiMH batteries retain their charge for many months and are normally sold factory-charged about 70% of their rated power. Rechargeable batteries are used in battery storage power stations for load-leveling (storing electric energy during periods of low demand for usage during peak periods) and clean energy applications. Load-leveling lowers the maximum power of a plant and it can produce, lowering capital costs and eliminating the need for peaking power plants. Here, the battery is connected to the dc-link of the converter in STATCOM for energy storage management. Thus the Proposed method is very effective while comparing the traditional methods. The upcoming section explains Consortium time based algorithms of STATCOM damping controller to find the most relevant and optimistic results.

3.3 Consortium time-based algorithms of STATCOM damping controller:

In this proposed the tuning of power controller parameters of STATCOM via Consortium time domain-based algorithm works with a population of current approximations (individuals) for time domain that are drawn at random and from which improvements are sought for system damping oscillations.

Individuals are encoded as strings using a specific alphabet, such as the binary alphabet {0, 1}, so that string values can be uniquely mapped to the decision variable domain. The decision variable domain is uniquely mapped. Individual performance is assumed based on the objective function that characterizes the problem to be solved once the decision variable domain representation of the current population has been calculated. It is also possible to represent the strings in the solution using the variable parameters directly.

A controlled shunt current source can be used to represent STATCOM. The STATCOM current is proportional to the terminal voltage and can be written as:

$$\mathbf{I}_{statcom} = \mathbf{I}.\,e^{J(\delta_w \pm 90)}$$

Where $\mathbf{I}_{statcom}$ is the STATCOM current.

I is the injected Current.

Inductive and capacitive modes are indicated by positive and negative signs, respectively. The voltage magnitude ($\mathbf{V}_w$) and angle of bus m (δ_w) in capacitive mode can be expressed as:

$$V_w = \frac{E' \cos(\delta - \delta_w) + VX_a cos\delta_w X_a X_b.\mathbf{I}}{X_a + X_b}$$

$$\delta_w = tan^{-1}\left(\frac{E' X_a sin\delta}{VX_a + E' X_b cos\delta}\right)$$

Where X_a and X_b are the membership function for input variables.

V is the injected Voltage.

The internal voltage, infinite bus voltage, STATCOM bus voltage, internal angle, and STATCOM bus angle are represented by **E', E, $\mathbf{V}_m$**, δ, δ_w respectively.

The output power of the machine can be written as:

$$P = \frac{E'V_w}{X_a}\sin(\delta - \delta_w)$$

$$P_{load} = V.I$$

Where P_{load} is the load power.

Table 1 Critical Clearing Time

Controller	Non-Controller	Fuzzy Logic Controller
CCT(Ms)	175	186

The frequency and range of oscillations are reduced when FLC is used for STATCOM. When transient stability is calculated, it means that increasing CCT will make the system more stable and will dampen oscillations more quickly. As a result, the load power and time characteristics were determined. Thus the proposed Consortium Time-Domain based Optimization Algorithm, the power controller parameters of STATCOM has tuned, which has the strong ability to find the most relevant and optimistic results. Thus as whole, the proposed work effectively mitigates the system damping oscillations.

This proposed method develops control strategy of STATCOM for damping power system oscillations. First the fuzzy controller design and its parameters adjustment are expressed. Then the proposed system is first examined without the use of STATCOM, and the critical clearing time is determined. The STATCOM is then subjected to FLC. In this paper, F_NIDC is deployed here to achieve an abrupt progress in the transient stability along with fault clearing time.

4 Result and Discussion

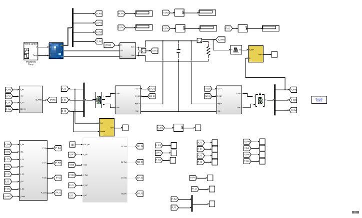

Figure 4. Design of the Proposed System

In this method, PV panels are connected to the converter's DC link as shown in figure 4. A voltage and current sensor will then be used to measure the voltage and current, respectively. The DC link is then connected to induce current, which flows through the load side. A Fuzzy Logic controller is used to reduce oscillation in the STATCOM-linked power system. In addition, an MPPT PNO controller is connected between the battery and the super capacitor for energy storage. To achieve the highest solar cell efficiency possible, the Maximum Power Point Tracker (MPPT) System Perturbation and Observation (PNO) controller used to achieve the operating point (OP) of a photovoltaic generator system (PGS) should be adjusted. As a result, the proposed system keeps its stability and efficiency for energy storage. The upcoming section explains about the result and discussion of the proposed method.

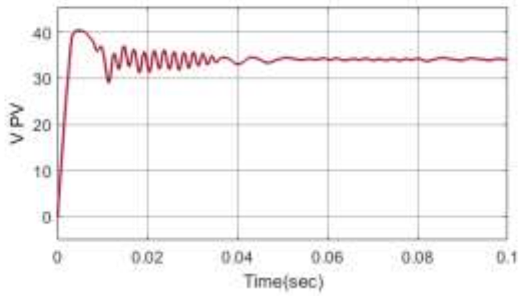

Figure 5. PV Voltage & Time Characteristics

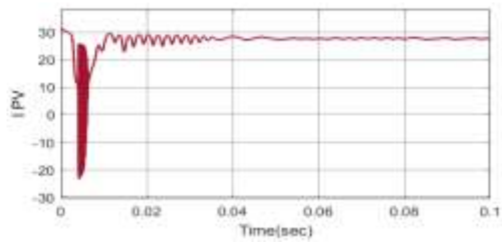

Figure 6. PV Current & Time Characteristics

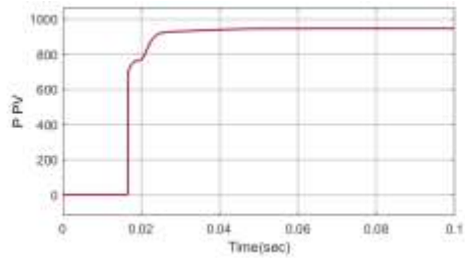

Figure 7. PV Power & Time Characteristics

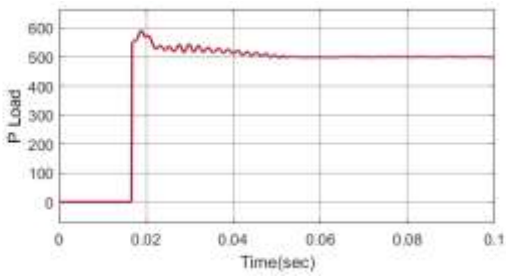

Figure 8. Load Power & Time Characteristics

The use of FLC for STATCOM reduces the frequency and range of oscillations, as shown in fig.8. When transient stability is derived, it means that increasing CCT will make the system more stable and that oscillations will be damped faster. Thus the Load power and time characteristics obtained.

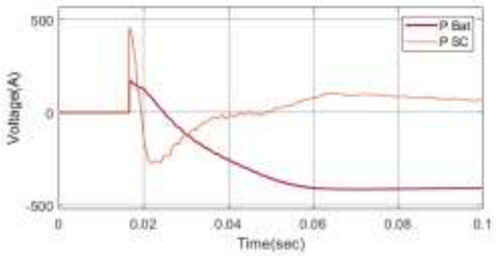

Figure 9. Voltage vs. Time Characteristics of Battery &Super Capacitor

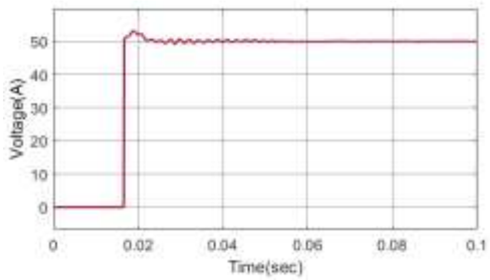

Figure 10. Voltage vs. Time Characteristics (Transient stability Improvement)

Figure 5, 6 and 7 shows oscillations in PV panel voltage, current and power. As a result, it is risky. Figure 8 shows that under the proposed F NIDC conditions, the load power is stable. Figure 9 depicts the voltage and time of the battery and super capacitor. In 0.1 seconds, the battery's voltage is reduced to -250V. Without any controllers, the voltage level of the super capacitor is suddenly increased to 450V in 0.015 seconds. As shown in Figure 10, the system is stable after the proposed conditions are applied. Figure 10 depicts the outcome of combining the proposed method with a fuzzy logic controller.

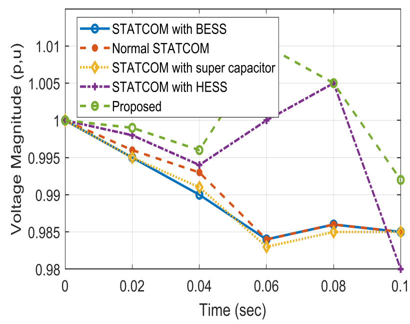

Figure 11. Comparision of proposed method with BESS, STATCOM, Super Capacitor and HESS

The magnitude and time characteristics of existing and proposed results are compared in Figure 11. When comparing other methods such as BESS, STATCOM, Super capacitor, and HESS, the graph shows that the magnitude of the voltage increases. When compared to other methods, the proposed method has a significant improvement in transient stability.

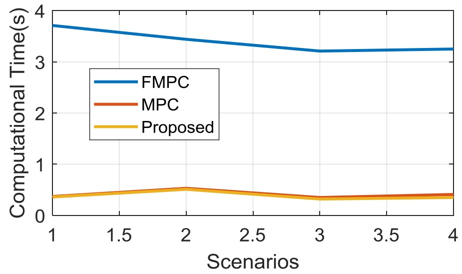

Figure 12. Comparision of Proposed method with FMPC and MPC (computational time vs. Scenarios)

Table 2 Computational Time

Scenarios	FMPC	MPC	Proposed
1	3.71	0.37	0.36
2	3.44	0.53	0.51
3	3.21	0.35	0.32
4	3.25	0.41	0.35

In Figure 12, the results of FMPC, MPC, and the proposed F NIDC are compared in terms of computational time and scenarios. The graph shows that the Computational Time decreases when compared to other methods. As a result, the proposed method Its computational time is significantly reduced when compared to other methods.

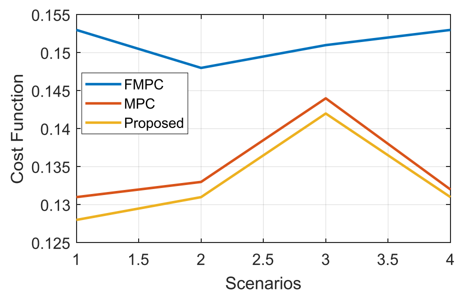

Figure 13. Comparision of proposed method with FMPC and MPC cost function vs. scenarios (Cost function vs. Scenarios)

FMPC, MPC, and the proposed F_NIDC results are compared in terms of computational time and scenarios in Figure 13. When compared to other methods, the cost function decreases, as shown in the graph. As a result, the proposed method is effective. When compared to other methods, its cost function is significantly reduced.

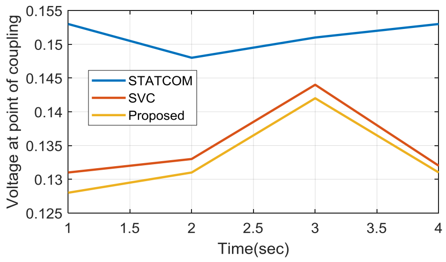

Figure 14. Comparision of proposed method with STATCOM and SVC (Voltage at point of coupling vs. time)

The results of STATCOM, SVC, and the proposed F NIDC are compared in Figure 14. The Voltage at Point of Coupling decreases when compared to other methods, as shown in the graph. As a result, the method proposed is efficient. Its Voltage at Point of Coupling is significantly lower when compared to other methods.

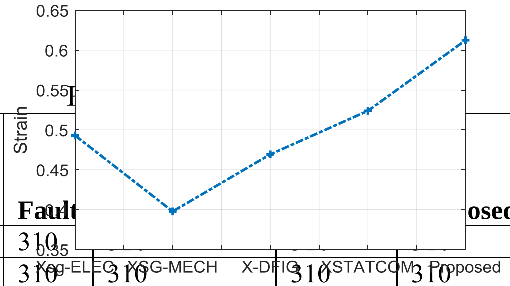

Figure 15. Comparision of Proposed method with Xsg-ELEC, Xsg-MECH, X-DFIG, XSTATCOM

Table 3 Strain

	Strain (Damping)
Xsg-ELEC	0.493
XSG-MECH	0.3978
X-DFIG	0.4693
XSTATCOM	0.5239
Proposed	0.6124

The proposed method is compared to Xsg-ELEC, Xsg-MECH, X-DFIG, and XSTATCOM in Figure 15. When compared to existing methods, it shows that the proposed method has a high damping.

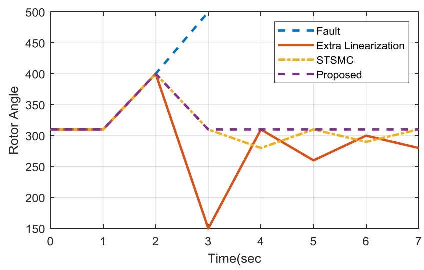

Figure 16. Comparision of Proposed method with Fault, Extra linearization and STSMC

Table 4 Rotor angle

Time (sec)	**Fault**	[illegible]	[illegible]	**[illegible]osed**
0	310	[illegible]	[illegible]	[illegible]
1	310	310	310	310
2	400	400	400	400
3	500	150	310	310
4	-	310	280	310
5	-	260	310	310
6	-	300	290	310
7	-	280	310	310

Figure 16 depicts the proposed method in comparison to Fault, Extra linearization, and STSMC. When compared to other methods, the graph shows that the proposed method is superior. Oscillations in the rotor angle occur at 2 seconds. The oscillations will be cleared after 3-7 seconds of damping. So the proposed method is very effective for improving transient stability.

5 Conclusion

In this Paper, provides an Optimized STATCOM via Efficacious Energy Storage Model in order to stabilize the power system. In this case, a battery storage system is combined with a super capacitor to serve as an energy storage scheme (ESS). It has been connected to a STATCOM in order to stabilize and mitigate system oscillations. It effectively mitigates a wide range of power system disturbances that are unavoidable. Furthermore, in order to improve the damping of system low frequency oscillations via NIDC, optimization issues must be addressed. To do so, the STATCOM power controller parameters must be fine-tuned using the Consortium Time-Domain based Optimization Algorithm. It has a strong ability to find the most relevant and hopeful outcomes. As a result, the proposed work effectively mitigates system damping oscillations with utmost transient stability by averting all those disturbances that occur in power systems using optimized parameters, which improves fault clearing time at the same time. Stabilizing the transient stability problem and damping system oscillations in a power system are thus critical for the safe operation of today's heavily loaded power systems. As a result, a novel design is proposed in this paper to implement such a system.

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