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Flexible AC Power Control in the Distribution System by Control of Solar PV and Battery Units

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***Abstract*— The steady-state and dynamic phases of operation can both be improved, the transmission corridors have been controlled using FACTS and flexible AC systems. To provide variable AC power flow regulation in the distribution corridors of an MV distribution system, Using the FACTS idea, this project suggests extending power distribution networks. The management of renewable energy sources (RERs) and batteries as a type of energy storage will be the main focus. The distribution network operator (DNO) can use the suggested FACPFCS outputs to help with peak shaving, supporting voltage and amperage, reducing long line sag, grid mitigation of reverse power flow, relieving congestion, delaying distribution upgrade, and a storage bus with regulation that can act as a load or a generator.**

***Index Terms*— FACTS, Distribution networks, DSTATCOM.**

I. INTRODUCTION

A novel application and control for power electronics-based technology called the Flexible AC Transmission System, or FACTS, is intended to improve power transfer and control capabilities during transmission, according to the FACTS Working Group IEEE Task Force. In light of the widespread adoption of power electronics centre technology-linked automation, the long and short-term benefits of FACTS are appealing. FACTS
Technology can increase dependability while reducing the cost of power transmission. Furthermore, by adding reactive power to the grid in the proper amounts, FACTS devices enhance the grid's quality of power and transfer effectiveness. As the use of FACTS technology in electrical networks increases, devices called as Flexible AC Distribution System are being deployed.
The possibility of utilising FACTS in distribution networks to lessen the detrimental effects of the erratic power produced by multiple PV solar systems is investigated. The consequences of voltage sag can be reduced by using FACDS equipment; other FACDS topologies and controls are being examined. The use of FACTS to control electricity flows in distribution network systems and minimise issues with power quality is also thoroughly examined. Also covered in depth is how using the voltage stability in distribution networks connected to wind

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farms may be improved via FACTS devices. However, the challenges are summarised as follows while utilising FACTS to control power flow in distribution systems as opposed to gearbox systems:

a) Given that R/X ratios for gearbox lines are often lower than those for distribution lines, the load flow analysis may not match up ;
b) Because More distribution lines are present connecting to a transmission system node than there are transmission lines, there are more lines that need to be regulated;
c) The distribution system often contains many small distributed renewable energy sources, but Only very big wind or solar farms often have links to the transmission system.

The answers to the aforementioned issues will be:

a) A claim that one can manage simulations. of and efficiently;
b) A method of regulation that combines to fully utilize the distribution of the power flows system, batteries with distributed solar-PV inverters devices are used.
c) A strategy that makes use of intelligent infrastructure for the distribution system and can coordinate system regulation.

The storage power flow controller (SPFC) concept is presented in order to define FACDS. Essentially a shunt-connected BESS with built-in microprocessor controllers, the SPFC that is being proposed. The results of the studies show that the SPFC is a good choice for load levelling, reactive power compensation, and power flow management in distribution corridors due to its quick response. A demonstration of the accompanying phase-shifting controller and current controller's abilities to compensate for shunt reactive power, manage the phase angle, and correct for voltage drop in the hysteresis band is given. However, these systems require specialized equipment installation, calibration of the criteria for control, upkeep, and coordination with the distribution system. The use of BESS inverter systems as unified power flow controllers (UPFCs) to manage the active and passive power flow is being looked into. Its applications, however, are intended in transmission routes and combine a perfect economic dispatch. The results of a thorough investigation into regulation of networks for transmission and distribution with the employment of power electronic inverters in a flexible manner, as well as an analysis and the power electronic interfaces' testing technological potential for BESS reveals increased availability of the electrical distribution. The suggested interfaced controllers for multiple input-multiple output inverters manage the power flow paths can provide operating fluidity. Additionally Flexible DC distribution is an idea techniques is discussed, including the utilisation of BESS converterss).

However, those control devices are susceptible to a wide range of operational limitations because they function independently as stand-alone controllers. In grid-level rich renewable energy systems, the use of optimisations and controls to reduce voltage and power variability has been studied. It is suggested that Renewable DG units and BESS use cooperative controls in order to lessen the AC grid's and DC distribution systems' power fluctuations. Model-free and model-based optimal controls are two categories in which these controls are formulated.

However, there is no discussion of how to implement such controllers in the case of many distribution channels. It is crucial to emphasize that because the contribution depends primarily on coordinated controls, a comprehensive analysis of the literature on optimization strategies has not been provided. This article promoted developing a revolutionary technique utilizing dispersed generation, such as RERs and BESSs, in order to improve the ability to operate the distribution system and transmit electricity.

This was constructed on the foundation of previously implemented FACTS in distribution systems, their proposed use at transmission networks, conceptualized Cooperation controls for renewable DG units, and BESS coupled to inverters. Additionally, it includes a mechanism for coordinated operation of the appropriate RER and BESS inverter. Adjusting the control set point when a distribution system is presents operating characteristics that are inherently changing.

II. Literature Survey

A. Evaluation Of Capacitor Placement

For the support of reactive power, capacitors were positioned much closer to the substation in the 1950s. Later, in order to maximise benefits, the capacitor was positioned closer to the load. Because there were no sophisticated computing resources in the past, the author proposed an analytical method based on calculus. To speed up processing, they adopted some approximations. Neagle and Samson's (1956) initial research on the best location for a capacitor bank under evenly and unevenly distributed loads. For a uniform load, they advised positioning the capacitor bank 1 (1/2) (capacitive kVAr/System kVAr) absent the primary substation.

For the placement of the capacitor in the system of radial distribution, Baran and Wu (1989) had programming in mixed integers. Chis et al. (1997) used heuristic search techniques to select more sensitive nodes for the capacitor's ideal location and size in order to maximise the system's net savings.
Genetic algorithms were developed by Das (2002) and Levitin et al. (2000) to determine the ideal size of fixed and switching capacitors at various load levels. A fuzzy-based decision maker was added to the supervisory control and data acquisition system (SCADA) by Mohammad et al. (2007) to determine the appropriate capacitor needed to improve the power factor relative to the parameters that were measured. Particle swarm optimisation was suggested by Prakash and Sydulu (2007) to determine the ideal capacitor bank size and reduce system power loss. For the purpose of compensating for reactive power, Antunes et al. (2009) introduced the best location for a capacitor in a Using the non-dominated sorting genetic algorithm, a radial distribution scheme. Rao et al. (2011) offered plant growth optimisation for appropriate placing the capacitors to increase voltage and decrease power loss profiles.Raju and others (2012) The direct search technique was used to find the best location and size of switches and fixed capacitors with the goal of increasing net savings and minimising system power loss. We investigated the IEEE Radial distribution systems with 22, 69, and 85 buses.
As of Nojavan et al. (2013) A approach to mixed-integer nonlinear programming is recommended to determine where and how big the capacitor should be in order to avoid power loss and maximum net savings.. The Ant colony optimisation technique was created by Kaur and Sharma (2013) to overcome the problem with how capacitors are placed in radial distribution systems. Bagherpour and Taher (2013) presented the colony of hybrid honey bees optimisation technique to handle placement of capacitors in radial distribution systems using IEEE 25-bus and 37-bus in order to restrict power loss and keep total harmonic distortion at a minimum.

B. Evolution Of Distributed Generation

In this section, the gradual evaluation of distributed generation is analyzed. The first person to solve the Distributed generation in the distribution system by Rau and Wan, (1994). To determine the ideal DG size at a candidate location, they devised the generalised reduced gradient approach.
Willis and scott (2000) had introduced 2/3 rule to calculate the ideal size and location of DG with uniformly distributed load. The 2/3 rule which is used for DG placement to determine the best location for the capacitor. Griffin et al. (2000) introduced heuristic iterative search to minimize the power loss using B loss coefficient. It is very easy to understand and it is an iterative method but it fails to give accurate results. El- khattam et al. (2004) introduced heuristic cost benefit analysis to reduce operating expenses, investment cost, loss of system power but it fails to produce the optimal solutions. Mardaneh and Gharehpetian (2004) In order to increase system reliability, DG allocation was done using the GA method.
Gozel et al. (2005) had presented analytical approach with the help of exact loss formula in order to reduce power and feeder loss. This method is very simple and easy to use and It could lead to an incorrect answer for a real-time system. Acharya et al. (2006) utilised an analytical approach to establish the ideal size and an approximate loss calculation to determine the ideal position.
Borges and Falcao (2006) had proposed GA to minimize the network power loss and maximize benefit of DGs units. They worked with the continuous and discrete parameters. Their computational time is high.

C. Evolution Of DSTATCOM

Jazebi et al. (2011) had first introduced the DSTATCOM allocation in the distribution system for the sake of power loss minimization. They suggested to place DSTATCOM after reconfiguration for the better power loss minimization. Since the distribution system suffers from high X/R ratio, the Gauss-seidel method which was proposed by them for load flow is not suitable for analysis.
Immune algorithm was proposed by Taher and Afsari (2014). for the placement of DSTATCOM in distribution setup that will reduce overall power loss, size of installing DSTATCOM and maintaining the current and voltage limits. Since there is no comparison for single DSTATCOM placement, they compared their work with two different algorithm by themself.
Devi and Geethanjali (2014) had proposed Particle Swarm Optimisation algorithm for DG and DSTATCOM deployment sizing to reduce the system's active power loss. The ideal position for the DG and DSTATCOM is determined using the updated Loss Sensitivity Factor.
Since there is no comparison for their work, they solved the DG and DSTATCOM problem with two different way so as to prove the correctness of the results. Initially they solved the DG's location and size and DSTATCOM using PSO algorithm and later on again they solved the DG and DSTATCOM placement using Modified LSF and PSO which was used to validate their results.

III. Flexible Ac Power Flow Control In Distribution Systems

The number of new consumers and industrial facilities is growing, which is causing a dramatic increase in energy consumption within the distribution system. As a result, the distribution networks typically run at full capacity, which results in severe power loss. It's crucial to provide the user with high-quality power. Losses happen as electrical energy travels the consumer via transmission and distribution networks, starting at the generating station. The creation of new electricity requires substantial up-front capital investments, lands, etc. Losses happen as electrical energy travels out of the power plant to the customer through transmission and distribution networks. In order to avoid these issues, new power generation includes using existing electricity as efficiently as possible.

The voltage profile enhancement and power loss reduction processes must be improved for the distribution system's operation to be optimised. substantial up-front capital costs, acreage, etc.

FACPFCS, a flow of AC power control system, aids in the optimisation of application of RERs and BESSs on the grid of distribution to deliver the desired results:

(i) Congestion control

(ii) decreasing lines' drooping,

(iii) decreasing the reversed flow of power on the grid;

(iv) Postponing the release of an update,

(v) Support for volt/VAr,

(vi) Peak time reduction,

(vii) Preventing RER service reductions,

(viii) A bus with storage control that can serve as a load demand or generator.

Additionally, a multi-mode control for applications can be used to implement the proposed FACPFCS.

The use of BESS inverter systems UPFCs, or unified power flow controllers to manage Both aggressive and passive power exchanges occur is being looked into. Its applications, however, are geared towards transmission corridors and combine a perfect economic movement. A thorough investigation of the use of power electronics inverters has produced findings that allow for flexible management of distribution and transmission networks, and the integrated BESS power electronic interfaces are examined and tested technical promise for more reliable power distribution.

Additionally, the concept of adaptive DC distribution techniques is put out (using BESS converters, for example). However, those control mechanisms are susceptible to a broad spectrum of operational limitations because they function independently as stand-alone controllers. At the grid level, It has been investigated how to use optimisations and controls to lessen variations in power and voltage in renewable energy systems. To reduce It is proposed to use cooperative controls between renewable DG units and BESS to reduce power oscillations between the AC grid and the DC distribution system.

Model-free and model-based optimal controls can be made using the formulations of these controls. However, the use of such controllers in the context of different distribution corridors is not considered, only their implementation methodologies. Since this study's contribution primarily calls for coordinated controls, it's crucial to note that there isn't an evaluation of optimisation strategies in the extensive literature. The recommended FACPFCS can potentially be used as an application platform for multi-mode control.

IV. Simulation Of Flexible Ac Power Flow Control In Distribution Systems

The FACPFCS's intended control approach continuously looks for a temporal horizon where a preventive measure can be implemented. It could be adjusted to take into account the load, erroneous solar-photovoltaic forecasts, and the distribution system's inherently changeable characteristics.

Only steady state functioning, or FACPFCS when used in conjunction with radial dispersion networks, is functioning normally. The suggested method will deal with this. The method the FACDS dynamic state operation can be added with a small modification.

In a typical object-oriented control system, data acquisition updates the command model. In consideration of the constraints imposed by the controller and system, as well as the specified objectives, The integrated solver then creates an agenda that includes dispatch control parameters. The control action would be carried out using a method of implementation with a vanishing or stable horizon. After that, the relevant controller parameters will be modified. The way controls are put into place is the fundamental distinction between this method and object-oriented system planning method. However, this common strategy has a severe drawback in terms of autonomous sequential execution.

Because there is currently no way to adequately gather control parameters prior to performing control operations, especially in modern distribution systems, it may not offer a sufficient solution for all fundamentally variable system states.
This has a significant impact on the implementation of controls and may lead to Object-oriented controls may not work as intended due to controller hunting. The suggested method ensures an effective result by allowing for integrating control coordination in accordance with the network operator's specifications.

A. Concept Of The Problem

A example distribution approach is in Fig. 1 and can be used to explain the theoretical underpinnings of the suggested technique by the FACPFCS. [8].
Vi and Ii are the amplitudes of the current and voltage at the system's connection to the voltage source inverter (VSI). The BESS or solar PV interface is provided by this inverter.

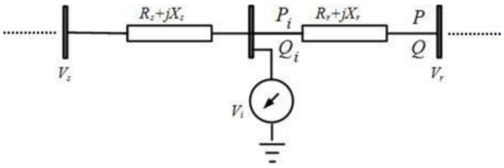


Fig. 1. An example distribution system's topology.

The power flow equations from [15] have already been expanded to incorporate VSI devices in a radial network. The following are the sets of relevant equations that take the understudied line segment into account for power flows:
While maintaining the internal voltage of the system's set range, the remote power sources (P and Q) can be controlled. Additionally, by effectively managing the inverter's power or current injection, various operational and system requirements can be met. When linked, In the power flow equations, the regulated energy storage devices take the role of a generator or load.
The formulation of the problem's governing factors is presented in (1).
(a) The BESS inverter's active power reference controllers for pBESS,
(b The reactive power reference controllers of the BESS inverter, or qbess,
(c) Reactive power reference (qpv) controllers for solar-PV inverters
These are the FACPFCS equations: (2) through (6).Reference values that are required and are always positive are integrated in order to lessen grid-connected reverse power flows (P1, Q1). The descending nodes are represented by nodes 1 through n, with node 1 serving as the slack node. Each node in the distribution system can be distinguished from the others by how they relate to the ith and jth nodes, respectively, in a set, N. To allow for both forward and backward power flows, Power flow (Pk, Qk) controls have reference values that are defined in accordance with (3).
The sole distribution path that is linked to the slack bus and guards against It is the reverse power flow.(2) through (6) list the equations of the FACPFCS. To lessen The essential Reverse power flows (P1, Q1) to the grid are integrated as reference values (P1/ref, Q1/ref), which are always positive.
The downstream nodes are represented by nodes 1 through n, with node 1 serving as the slack node. The position of each node in the distribution system in relationship to the ith and jth nodes, respectively, in a collection of nodes, N, serves as the node's unique identification. (3) Defines reference settings (Pk/ref, Qk/ref) for power flow (Pk, Qk) controllers that the ability to move power both forward and backward. The slack bus's only connected distribution corridor that inhibits reverse power flow is this one.
In (7) through (8), the BESS power and energy limitations are listed, where E0 denotes the power that was stored in the BESS at time t-1. The pace at which the BESS charges and discharges is continuously managed to avoid exceeding the SOC, active, and reactive power ceilings.
Reactive power capability restrictions for solar-PV inverters are listed in (9), based on inverter and PV generating power limitations.
The distribution system node voltages, Vi, and the (Pj, Qj) line power flow limitations are listed in items (10) through (11):
The models for Impedance, Current, and Power loads are also included in the formulation discussed in (12) through (13) [18].

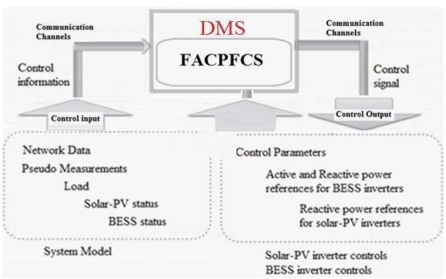
The outputs from the solar-PV units are used to transform the aforementioned equations into the form shown in (14) and the BESS serving as the control variables. For the purpose of incorporating the FACPFCS idea. The parts of each node that correspond to the different kinds of nodes are identified by the functions F(x)a through F(x)h.
Fig. 2 shows a variety of node types related to the phraseology provided by (14). The corresponding nodes in any distribution strategy in a real network are the example nodes. The estimated equivalent secondary circuit is considered while modelling a substation transformer. The subsets of the equation for F(x) at each node are listed below.
The subset of equations known as F(x)a in Fig. 2 (a) is connected to the secondary bus for the substation shown. It is possible to control P1 and Q1 are the line power flows along the distribution corridor shown in Fig. 2(a) while preventing reversing electricity flow on the grid.
By establishing the P and Q references (2).
The subset of the F(x)b equation connected to a load bus can be built using the right variables and parameters, as shown in Fig. 2(b). The active and reactive power components of the load must also be considered.
The BESS and solar-PV systems' active and reactive power components, as well as other significant components, are recognised by suitably updating F(x)b. This holds true for both the set of F(x)d equations connected to the solar-PV and the portion of the F(x)c equations linked to (14) and the BESS buses. The BESS instance will receive a new variable with the name Ea/bess.
Based on The additional equations in the formula provided by (14) were built to account for the function of the BESS, which is discussed, and the inverter capacity limits with safety margins of K1 and K2, which are provided by (15) and (16).

B. Control Action

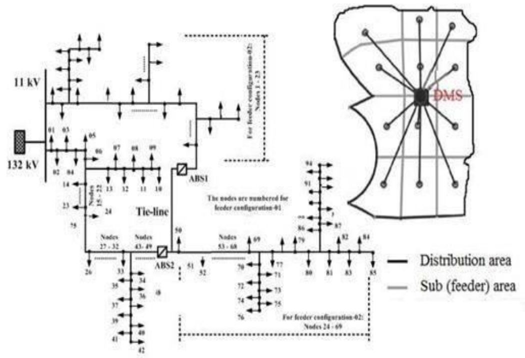
The receding horizon control technique must be utilised to govern all state variables on the control platform in (14) in order to implement the suggested strategy. The strategy for reversing the horizon, The present start of control state at time t, and throughout the ensuing Instead of employing a control strategy has a constant horizon. The control problem is addressed when the control sequence (t, t+T-1) begins in the present and finishes in the future. Unexpected occurrences that might take place during the control interval are not meant to be taken into account by this method. The letter T stands for the entire control horizon.
Only then are the responses to the first action in the control sequence analysed. Control is then repeated after estimating the state obtained time t=t+1. An example of coordination as well as a brief description of the steps to build and resolve (14) are provided in the algorithm-pseudocode that follows. "Number of variables," or NV, refers to both state and control variables.

C. *Control Implementation*

The suggested controls can be developed and implemented as a using peer-to-peer communication and an improved distribution management system, an independent control unit in a feeder distribution system. (DMS) mentioned in [20], [21]. The controls envisioned for a smart distribution grid can also be implemented via distributed controls.
The usage of a control module is being considered, as shown in Fig. 3(a). To effectively coordinate the control of PV and BESS, it is possible to programme and enhance the module's control capabilities.
The chosen distribution corridors can always keep both active and reactive power flowing along with relevant inverters and sufficient battery energy storage. However, because this will be a very expensive operation, the control is only active when it is necessary for the specific use, such as congestion relief. In Fig. 3(b), the suggested actions are put into practice in a distribution zone. The distribution system shows a dot to represent a sub (feeder) area inside the distribution zone indicating the operation of the DMS-control module.



(a)



(b)

Fig. 3. Proposed implementation: (a) a proposed control module, and (b) multiple control modules in a distribution area.

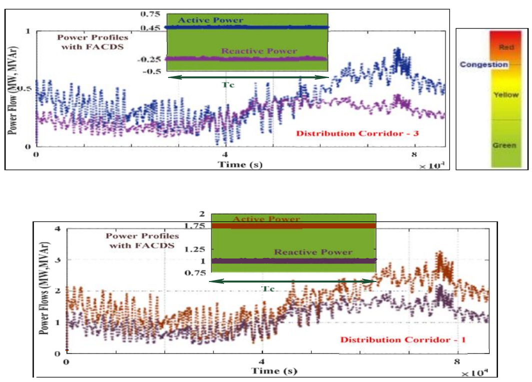
V. MATLAB IMPLEMENTATION

A. Matlab Simulation & Results

It makes concepts from various academic areas, including signal and image processing, control systems, communications, and computational finance, easier to visualise. SIMULINK makes it simple to build a computer simulation of a physical system and then swiftly simulate it. Simulink uses block diagrams to visualise models. Through the offered libraries, the user has access to a wide range of blocks that may be used to represent various events and control models for energy flows along corridors for distribution. BESS units, future energy distribution systems with advanced technology-based internal energy management systems advancements in The proposed approach can be implemented using inverter controls, technology, and smart grid features, offering the distribution network directors a variety of benefits.

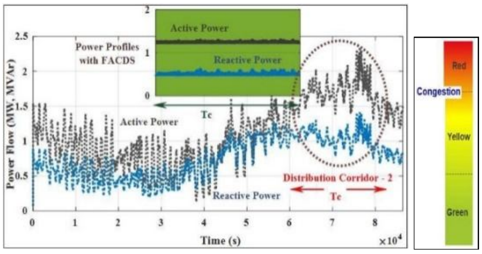
VI. RESULTS AND DISCUSSION

Simulations of the model MATLAB has been used to conduct all of the distribution scheme of tests regular activities (explained in Section II). As proof of concept for the suggested technique. The simulation case studies were created to show the various uses of the proposed FACPFCS, which includes peak shaving and provides the needed power management in distribution corridors, Long power lines' sag is reduced, and reverse power flow to the grid is minimised, and support for Volt/VAr. The proposed FACPFCS's suitability for power management in some crucial lines experiencing worrisome congestion (i.e., at a peak time) is given.
Accordingly, the reference values for the simulated power flow for the various distribution corridors are as follows: for the first distribution corridor, (P1ref, Q1ref) = (1.75MW, 1.00 MVAr); for the second distribution corridor, (|P28ref |, |Q28ref|) = (1.25MW, 0.50 MVAr); and for the third distribution corridor, (|P72ref |, |Q72ref|) = (0.45MW, 0. Based on the operators' past experiences in the control room, these values will be evaluated.



(a)

Rising power flows throughout the time period Tc (2.32 x 104 s) are shown in Fig. 6(a), which is for the second distribution corridor, and may result in congestion (red-state). The suggested course of action will therefore be implemented. It is important to notice that, at the time Tc, a similar occurrence is also happening with the third the test distribution system's distribution corridor.



(b)

The first distribution corridor, which is close to the secondary bus for the substation transformer, is where the power flows, are depicted in Fig. 6(b). Without any grid-connected reverse power flow, the control action in this instance regulates the first distribution corridor is where the power travels.

VII. Conclusion

This concept proposes that flexible AC Controlling battery renewable energy and energy storage resources allows for the regulation of a medium voltage distribution system's power flow in the distribution lanes. The suggested technique also contains a number of control features that are easily developed and implemented on a command platform built using the formulation and solution methods offered. There are two choices: solar-PV inverters and BESS. Using these control capabilities, which may also be used for supporting services suggested in this study, such as inverter oversizing if necessary, more efficiently.
Power flows in distribution corridors, according to the simulation results may be managed with the right combination of sustainable sources and BESS. The recommended approach can be implemented via technologies for distributing energy in the future, BESS units with advanced internal energy management systems, technological advancements in inverter controls, and smart grid featuress, giving the directors of the distribution networks a number of benefits.

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