OPTIMIZED DC-LINK CONTROL AND PROTECTION FRAMEWORK FOR SOLAR PHOTOVOLTAIC MICROGRIDS

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ABSTRACT : This work presents a cohesive strategy for DC-link voltage regulation and protection specifically designed for microgrid applications. The suggested method keeps the DC-link voltage stable during load changes and AC-side fault events. It also protects the DC-link in case of a short circuit in the DC section. A microgrid test model that followed IEEE 1547 standards was used in PSCAD/EMTDC simulation software to see how well this strategy worked. The system was tested under a variety of fault conditions, which made it possible to fully evaluate its performance. The simulation results show that the suggested method works to stabilize the DC link voltage during both AC- and DC-side disturbances, whether the system is connected to the grid or not. The scheme can keep the DC-link's voltage control and protection strong across a wide range of operating conditions and fault conditions.

Keywords: AD-DC. Faults, DER,DC Link, VSI, DC and AC power

I.INTRODUCTION

A grid-connected microgrid connects renewable-based distributed energy resources (DERs) to the local distribution network. Its topology is different from that of traditional power systems because converters frequently change AC to DC power and power flows both ways between DERs and the utility grid. Some common DER technologies are solar PV, wind turbines, fuel cells, micro-hydroturbines, biogas systems, and gas turbines.The low-voltage DC output from solar-based DERs is first raised to a set DC-bus level using a boost converter. Then, a voltage source inverter (VSI) changes this DC voltage into AC power so that it can be used on the grid, as shown in Fig. 1 [4]. A typical VSI setup has a DC link with a bank of capacitors between the inverter and the boost converter. These capacitors help keep the power flow steady, make up for differences between the converter stages, and smooth out voltage ripples. Their main job is to keep the DC-link voltage stable during problems like load changes, faults, intermittent renewable generation, or inverter switching operations [5][6].

1.1 Solar Photovoltaic (PV) System

Introduction: A solar cell, also called a photovoltaic (PV) cell, uses the photovoltaic effect to turn sunlight directly into electricity. "Solar cell" usually means devices that are only meant to collect solar energy, while "PV cell" can mean devices that get power from different light sources. Modules or panels are made up of several cells that are connected to each other. These can be put together to make larger arrays that can generate more power. Photovoltaics is the branch of science and technology that deals with turning sunlight into electricity that can be used. Solar cell efficiencies vary greatly. For example, amorphous silicon cells only get about 6% efficiency, while commercial multicrystalline silicon cells get between 14% and 19%. Laboratory-grade multi-junction cells have gotten over 40% efficiency, and some hybrid systems have gotten over 42%.PV cells can be used in more than just large-scale power plants. They can also be used in small devices like solar-powered chargers, bike lights, and camping lanterns. Rechargeable solar battery chargers can charge things like music players, laptops, PDAs, and smartphones without needing electricity from the grid. Solar PV systems help the environment by replacing disposable batteries and cutting down on the use of non-renewable energy sources. They also lower operational costs.

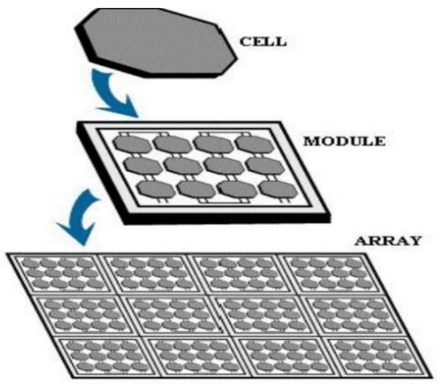


Figure 1. Solar PV Module diagram

Solar battery systems can automatically provide backup power when the main power supply goes out. This makes them a very useful tool for reducing reliance on traditional energy sources. You can get these systems in a wide range of sizes, from small ones that only make a few watts to big ones that make several megawatts. In the past, solar batteries were mostly used in remote areas or in big solar farms that needed a lot of energy storage. In recent years, though, solar battery modules that go on roofs and walls have become more and more popular.A solar battery usually has several photoelectric cells connected in a row on a substrate to make the right output voltage. The solar cell is the smallest working part. It turns sunlight into electricity directly with high efficiency, low operating costs, and no pollution.

1.2 How It Works

Photovoltaic (PV) cells, which are semiconductor devices that turn sunlight into electricity, are used in solar power systems. Photons hit the semiconductor and move electrons from the valence band to the conduction band, which makes an electric current. People know that crystalline silicon PV cells are very efficient and last a long time. Solar panels are made up of several modules that are connected in series or parallel. You can put these panels together in arrays to get the right voltage and power capacity. Cells are connected by internal wiring and connection pads. The module is made up of layers, including a glass front, encapsulation material, and a protective backing. Some photovoltaic (PV) systems use lens concentrators or sun-tracking mechanisms to focus sunlight onto the cells. This increases power output no matter what the weather is like. The coupling box sends the DC power to a rectifier, which then either stores it in batteries or changes it to AC so it can be used on the grid. Structural parts like headers, receiver tubes, and mounting systems make sure that the installation is stable and longlasting, especially on roofs. In big solar thermal systems, a group of heliostats (mirrors that follow the sun) sends sunlight to a central receiver, where the heat is captured and turned into electricity. Modern solar batteries are now long-lasting, affordable, and widely used because the cost of making them has gone down. Big PV systems can meet a lot of power needs for homes and businesses, but small systems are great for powering low-power devices like watches, cameras, cell phones, and portable lights, especially in rural or off-grid areas.

1.3 Uses

Portable Power: Built into everyday items like solar phone chargers, bike lights, and lanterns for camping. Utility-scale renewable power plants In developing areas, PV plants are taking the place of older fossil-fuel-based energy sources more and more. Off-Grid Solutions: A way to get reliable power in rural areas where the grid isn't available. Low-Power Electronics: Solar battery modules can directly power small devices like calculators, digital cameras, and GPS trackers. The use of solar power around the world has been steadily rising, from only 0.02% of energy use in 2008 to about 2% more each year. If people keep using solar energy at the same rate, it could become the most popular source of power in the next few decades.

II.LITERATURE REVIEW

1) A plan for controlling and protecting the DC-Link of a solar PV-based microgrid This study suggests a unified control and protection strategy for the DC-link in a solar photovoltaic microgrid. The plan is to keep the DC-link voltage stable during AC-side faults or load-switching events and protect it from short-circuit conditions. We put a microgrid test model, made with PSCAD/EMTDC and following IEEE 1547 standards, through a number of fault scenarios. The results show that the system keeps the voltage stable and protects the DC link whether it is connected to the grid or not.

2) Adaptive ROCOF-Based Islanding Detection for Different Types of Microgrids To solve problems with non-detection zones (NDZs) in current methods, an adaptive passive islanding detection method based on the Rate of Change of Frequency (ROCOF) is presented. The method changes the frequency and ROCOF thresholds to fit different microgrid setups by using phase-locked loop (PLL) tuning. The method works in MATLAB/SimPower for both generator-only and hybrid (generator, PV, storage) microgrids. It can reliably find islanding events, even when there is no power mismatch, and it can tell the difference between islanding and non-islanding events in a variety of situations.

3) Integrated control and protection for microgrid operation without any problems This paper describes a decentralized control and protection plan for running a microgrid in both grid-connected and islanded modes, following the IEEE 2030.8 standards. Under steady-state and dynamic conditions, the system keeps voltage and frequency within the ranges set by IEC 61727, IEEE 2030.8, and IEEE 1547. It has plug-and-play integration for DERs, ROCOF-based islanding detection, adaptive fault protection, and load-shedding that works when the voltage or frequency changes. Simulations in MATLAB/Simscape show that the

scheme lets the microgrid run smoothly in a variety of situations.

4) Protecting the DC-Link in Photovoltaic Systems Connected to the Grid To improve the performance of PV inverters when there are disturbances, a strong method for regulating DC-link voltage based on Linear Active Disturbance Rejection Control (LADRC) is suggested. The method uses an enhanced Linear Extended State Observer (LESO) to figure outhow much noise there is in real time and a Linear State Error Feedback (LSEF) to make up for it. This makes the system simpler by turning it into a cascaded double-integrator. Analysis in the frequency domain and tests show that stability and the ability to reject disturbances have both improved.

5) Lowering the Ripple Current in the DC Bus Capacitors of Cascaded Converters This study examines the reduction of ripple current in DC bus capacitors for cascaded two-stage DC/DC converters. The study looks at how different combinations of duty cycles and phase-shift angles between converter stages affect the RMS current in capacitors. The best phase-shift adjustments lower ripple current without needing extra sensing hardware, which makes energy conversion more efficient and extends the life of capacitors. A prototype shows that it can be up to 2.8% more efficient than the worst-case phase-shift scenario.

III.PROPOSED CUTTLEFISH OPTIMIZATION ALGORITHM

The Cuttlefish Optimization Algorithm (CFA) is a bio-inspired, population-based metaheuristic that mimics the cuttlefish's unique ability to change the color and pattern of its skin for communication and camouflage. This process is controlled by three specialized skin cells:

1. Chromatophores – Pigment cells that expand or contract to reveal or hide colors.
2. Iridophores – Reflective cells that bend and scatter light, creating shimmering colors.
3. Leucophores – Cells that reflect white light, contributing to brightness and background blending.

Working Mechanism

In CFA, these biological principles are modeled mathematically through two main processes:

1. Reflection – Simulates how light bounces off different layers of cells.
2. Visibility – Measures the similarity between the current solution and the best-known solution, guiding the search toward optimal results.The algorithm divides the population into four groups. Each group adopts a distinct exploration–exploitation strategy, balancing global and local search based on reflection and visibility. This hybrid approach enables CFA to effectively explore complex solution landscapes.

Applications of CFA

1. Feature selection for intrusion detection systems.
2. Network optimization for improved efficiency.
3. Medical diagnostics, e.g., feature selection for Parkinson's disease detection.
4. Control optimization in distributed generation using inverters.
5. Combinatorial optimization problems, such as the Traveling Salesman Problem (TSP).

Advantages of CFA

1. Achieves high classification accuracy with fewer features and reduced false alarms.
2. Computationally efficient compared to using the entire dataset.
3. Maintains robustness and stability in noisy datasets.
4. Produces concise and interpretable decision rules.

Sliding Mode Control (SMC)

Sliding Mode Control (SMC) is a nonlinear control strategy widely used in systems with strong nonlinearities, uncertainties, and external disturbances. Unlike conventional linear controllers (e.g., PID), SMC ensures robust performance in challenging conditions.

Advantages of SMC

1. Robustness – Maintains stability and performance under large parameter variations and disturbances.
2. Finite-time convergence – Ensures fast convergence of system states to the sliding surface.
3. Simplified dynamics – Once on the sliding surface, the system can be described by lower-order models.

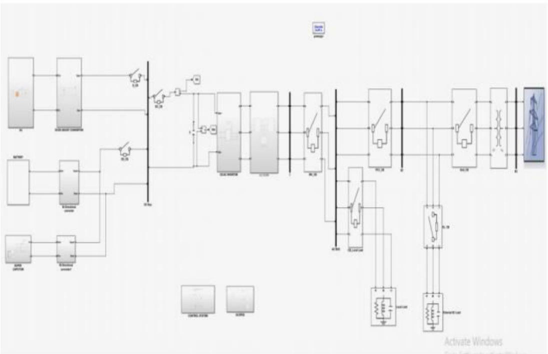
Applications

1. **Robotics** – Precise trajectory tracking under varying loads and disturbances.

2. **Power systems** – Voltage regulation and oscillation damping during load changes.

3. **Automotive systems** – Improved performance in ABS and traction control systems.

4.



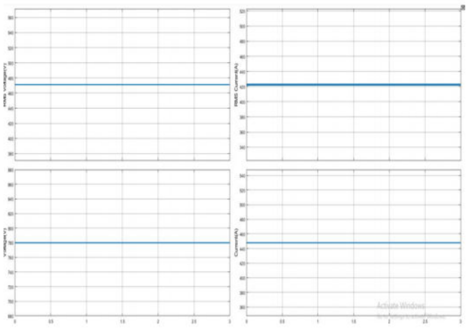


Fig. . (a) RMS voltage level at AC-side, (b) RMS current level at AC-side, and (c) voltage level at DC-link, (d) current level at DC-link during stable grid connected mode without any fault.

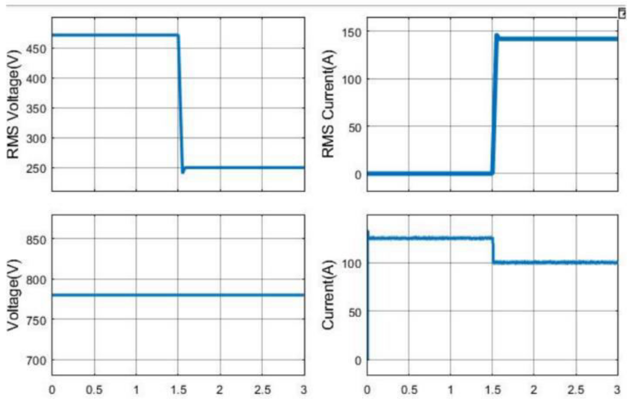


Fig. . (a) RMS voltage level at AC-side, (b) RMS current level at ACside, (c) voltage level at DC-link, and (d) current level at DC-link during grid connected mode with AC-side fault and with DC-link voltage control

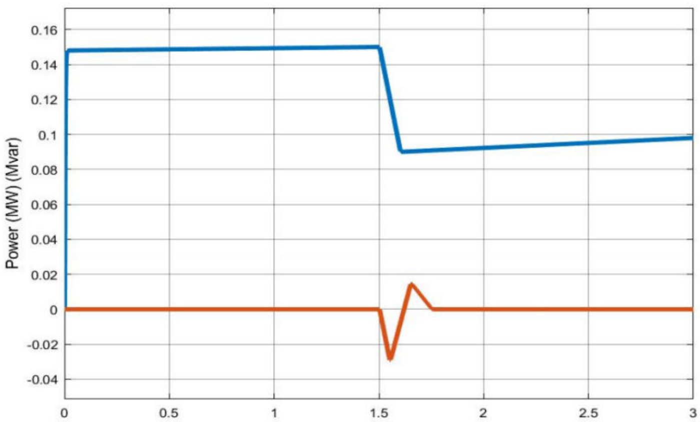
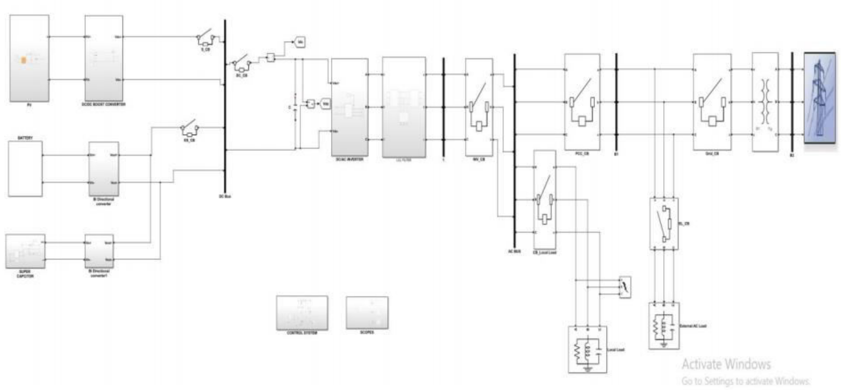


Fig. (c) inverter reactive, and active power level during grid-connected mode with AC-side fault and without DC-link voltage control.



Cuttle Fish Algarithem :

cd(tempdir)clc; clear;

%% === STEP 1: Define Plant === plant = tf(1, [1 10 20]);

Plant example. If necessary, replace with your own system.

%% === STEP 2: CFO Parameters === nFish = 30; % maxIter =

20; number of cutting fish Maximum iterations: dim = 2; Kp,

Ki, and lb = [0 0]; The lower bounds for [Kp, Ki] are [10

10]. Upper limits

% Randomly set the positions of the fish X = rand(nFish,

dim) .* (ub - lb) + lb; fitness = zeros(nFish, 1);

% Initial fitness evaluation for i = 1:nFish fitness(i) =

objectiveFunction(X(i,1), X(i,2), plant); end

%% === STEP 3: Main CFO Loop === for iter = 1:maxIter

[bestFit, idx] = min(fitness); bestFish = X(idx, :); %

Current best [Kp, Ki]for i = 1:nFish alpha = 0.1; % Random movement intensity

beta = 0.5; % Cutting motion intensity randFish =

X(randi(nFish), :); % Fish that are random

if rand < 0.5 % Exploration: go in a random direction

newX = X(i,:) + rand .* (randFish - X(i,:)) + alpha *

randn(1,dim); else

% Exploitation: an aggressive cut toward the best fish newX

= X(i,:) + beta * (bestFish - X(i,:)); end

% Check the bounds: newX = max(newX, lb); newX = min(newX,

ub);

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% Check the new fitness
newFit = objectiveFunction(newX(1), newX(2), plant);
% Avoiding predators: if newFit < fitness(i), then X(i,:) =
newX; fitness(i) = newFit; end
% Show progress by printing "Iteration %d: Best Fitness
= %.5f\n", iter, bestFit; end
%% === STEP 4: Show Results === Kp_opt = bestFish(1);
Ki_opt = bestFish(2);
fprintf('\nOptimized PI Controller Gains:\n'); fprintf('Kp
= %.4f\n', Kp_opt); fprintf('Ki = %.4f\n', Ki_opt);
% Save to the base workspace in MATLAB: assignin('base',
'Kp_opt', Kp_opt); assignin('base', 'Ki_opt', Ki_opt);
% Step response of the last controller
C = pid(Kp_opt, Ki_opt); sys_cl = feedback(C * plant, 1); t
= 0:0.01:5; step(sys_cl, t); title('Step Response of
Optimized PI-Controlled System'); xlabel('Time (s)');
ylabel('Output');
% === STEP 5: Change the Simulink PID Controller === --
Change these names to the real names of your model and
block -- modelName = 'dc_link_control_model'; Name of the
Simulink model: blockPath = [modelName '/PI_Controller']%
Path to the PID blockSet Kp and Ki in the Simulink block
try
set_param(blockPath, 'P', num2str(Kp_opt));
set_param(blockPath, 'I', num2str(Ki_opt));
save_system(modelName); fprintf('Simulink PID Controller
updated successfully.\n'); end
%% === FUNCTION OF THE OBJECTIVE: ITAE === J =
goalFunction(Kp, Ki, plant)
C = pid(Kp, Ki); sys_cl = feedback(C * plant, 1); t =
0:0.01:5; [y, t] = step(sys_cl, t); e = 1 - y; Error signal
J = trapz(t, t .* abs(e)); % ITAE calculation End
```

IV.CONCLUSION

A novel protection and voltage control strategy is developed to regulate the DC-link voltage and ensure protection during AC and DC fault events in a battery energy storage and solar PV-based microgrid. The strategy is evaluated under both islanded and grid-connected modes by introducing faults at the DC-link and on the AC side. Simulation results demonstrate that the proposed scheme effectively regulates the DC-link voltage during AC-side faults and provides reliable protection during short-circuit faults at the DC-link in both operating modes. Future work will extend the application of this scheme to wind turbine-based energy systems.

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