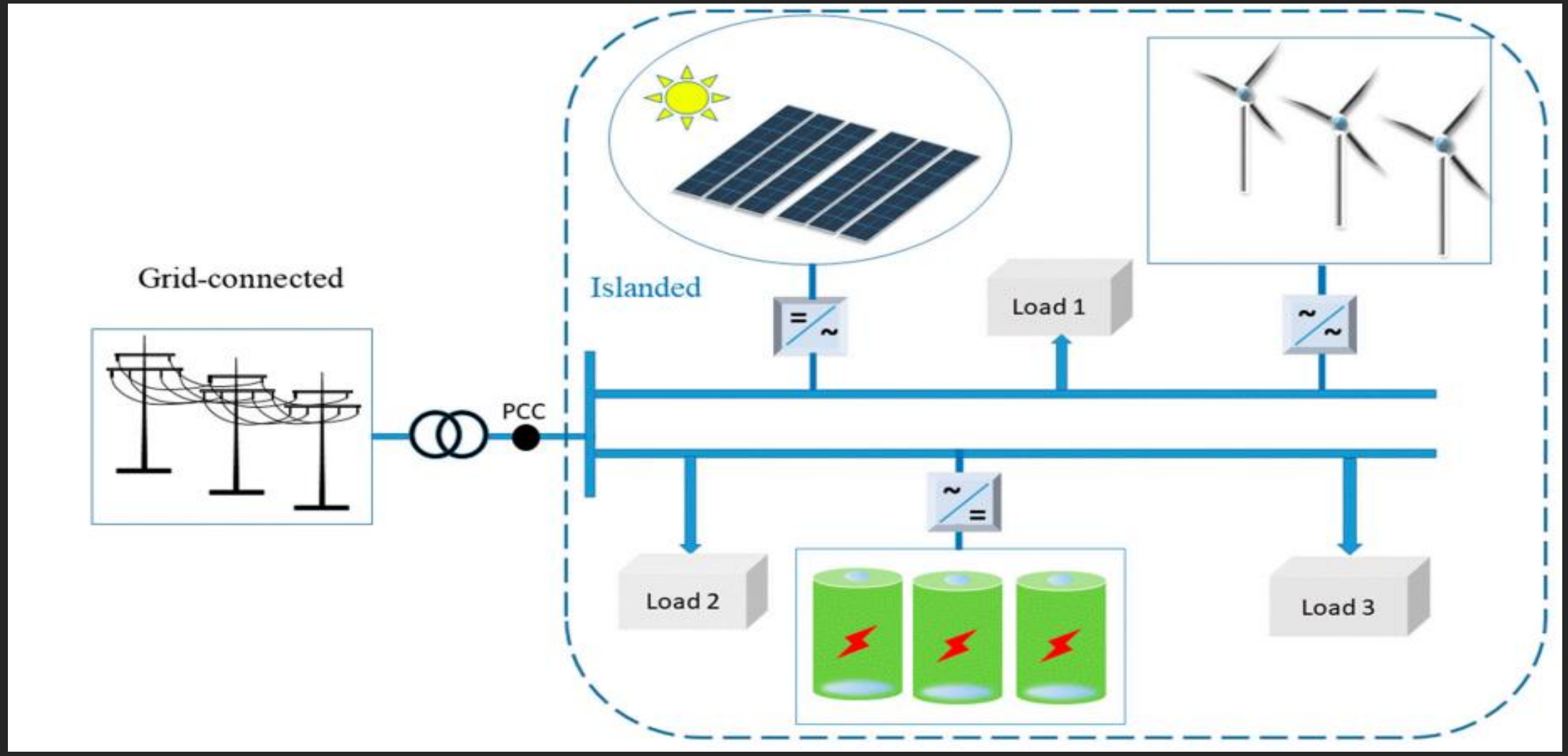
Recent Developments in Microgrid Protection

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Typical Microgrid Structure



Benefits of Microgrid

- Enhance power generation capacity
- Enabling localized generation at consumer sites
- Alleviate load congestion on the traditional grid of electricity
- Improved Energy Efficiency
- Reduces net energy consumption
- Better service quality and reliability

Micro-Grid Initiatives in India

S. No.	Project	Capacity	No. of villages/houses	Electricity price	Location	Types of sources
1	Sagar Island microgrid	26 kW	One (350 houses)	Rs 7 kWh	Sagar Island, Sundarbans, West Bengal	SPV + biomass + wind
2	Chhattisgarh Renewable energy development agency (CREDA)	500 PV systems	Roughly six (30,000 houses)	Fixed: 300 + five (monthly) 1–2 kWh	Chhattisgarh State	SPV
3	Decentralized Energy System of India (DESI) Power	260 kW PV systems	Roughly four (450 households)	Rs 5–12 kWh	Bihar (4) Madhya Pradesh (1)	Biomass
4	Dharnai solar city	100 kW	One (350 households)	12–14 kWh	Dharnai, Bihar	SPV
5	Husk Power System (HPS) Microgrids	82 system (32 kW each)	48 (3200 houses)	Connection: 100–200, 70/month per connection (15 W)	Bihar	Biomass
6	(OREDA)	2–4.5 kW each	27	Rs 10–30 per month	Orissa	SPV
7	West Bengal Renewable Energy Development Agency (WBREDA)	25–500 kW each	22 (50 houses)	Rs 6–30 kWh	West Bengal	SPV + biomass + wind

8	Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA)	1.2 kWp system	27 districts	Fixed: Rs 50/month + energy charges	Uttar Pradesh	SPV
9	Solar electricity company (SELCO)	1–14 kWp system	Roughly five	–	Karnataka	SPV
10	Alamprabhu Pathar Maharashtra Energy Development Agency (MEDA)	12,000 kW	50 houses + 40 commer-cial + agricultural	–	Maharashtra	Biomass+ wind
11	Gram Oorja	5–30 kWp system	30–40 houses	Rs 20 kWh	Maharashtra, Karnataka	SPV
12	Sikkim Renewable Energy Development Agency (SREDA)	10–25 kW	–	–	Sikkim	SPV + Minihydro
13	Amrita self-reliant villages	8 kW minihydro	One (30–40 houses)	–	Kerala	SPV + Minihydro
14	Mera Gao Power (MGP)	240 Wp systems	Roughly eight (250 houses)	Fixed: Rs25/week + energy charges	Uttar Pradesh	SPV
15	Biomass energy for rural India Project	500 kW	Roughly three (80 houses)		Karnataka	Biomass
16	Palm Meadows	30 kW	335 houses	–	Hyderabad	SPV

IEEE standards for Microgrid operation and control

Standard	Title/Description	Scope and objectives
IEEE 1547-2018	• Interconnecting Distributed Resources with Electrical Power Systems.	ü Characterizing various distributed resources interconnection issues, technical requirements, penetration level, etc.
• **IEEE 1547a-2020 Amendment-1:** For the adaptation of abnormal operating performance with more flexibility.		
IEEE 519-2014	• Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.	ü It addresses steady-state limitations. Transient conditions limits, power quality measure at the point of common coupling. Though it does not cover the effects of radio-frequency interference.
IEEE 2030-2011	• Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads	ü Established the smart grid interoperability reference model which defines three integrated architectural perspectives: power systems, communications technology, and information technology and also the application of engineering principles for smart grid interoperability of the electric power system with end-use applications and loads, etc.
IEEE P2030.12	• Guide for the Designing of Microgrid Protection Systems	ü It includes the design and selection of PDs and their coordination for different microgrid operation states (grid-connected, islanding and also transitions between modes).
• **IEEE 2030.7-2017** Standard for the specifications of microgrid controller		
• **IEEE 2030.100-2017** Recommended Practice for Implementing an IEC 61850 based Substation communications, Protection, Monitoring and Control System.		
• **IEEE 2030.9-2019** Recommended Practice for the planning and Design of the microgrid.		
IEC 61850	• Communication networks and systems for power utility automation	ü Support the identification of services and data models, application protocols, mapping" of data objects, etc.
■ **IEC 61850-6-2009/ Amendment-1:2018:** Configuration language for communication in electrical substations related to IEDs.		
■ **IEC 61850-7-2:2010:** Communication networks and systems for power utility automation.		
■ **IEC 61850-7-4XX (XX:10-2012, XX:20-2009):** [Hydroelectric power plant modeling, communication for monitoring and control, modeling of DERs].		
■ **IEC 61850-8-1-2011/ Amendment-1:2020:** Mapping to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3.		
■ **IEC 61850-80-X: (X:1-2016, X:3-2015, X:4-2016)** Guideline to exchange information using IEC 60870-5-101 or IEC 60870-5-104.		
■ **IEC 61850-90-X (1-8): (X:1-2010, X:2-2016, X:3-2016, X:4-2020, X:5-2012, X:6-2018, X:7-2013, X:8-2016)** [Communication between substations, communication between substations and control centers, condition monitoring, Network engineering guidelines, synchrophasor information transmission, distribution automation system, models of ESS, and EVs schedules].		
IEC 61400 (series)	• Wind energy generation systems	ü Used in wind turbine generation system and deals with safety requirements, quality assurance, design, installation, operation and maintenance, etc.
IEC 61727	• Photovoltaic (PV) systems - Characteristics of the utility interface	ü Applies to utility-interconnected PV power systems operating in parallel with the utility and utilizing solid-state non-islanding inverters for the conversion of DC to AC.
IEC 60364 (series)	• Low-voltage electrical installations	ü Covers general requirements for safety services, protection against electric shock, protection against overcurrent, earthing arrangements and protective conductors, etc.

Protection related Challenges faced by AC Microgrids

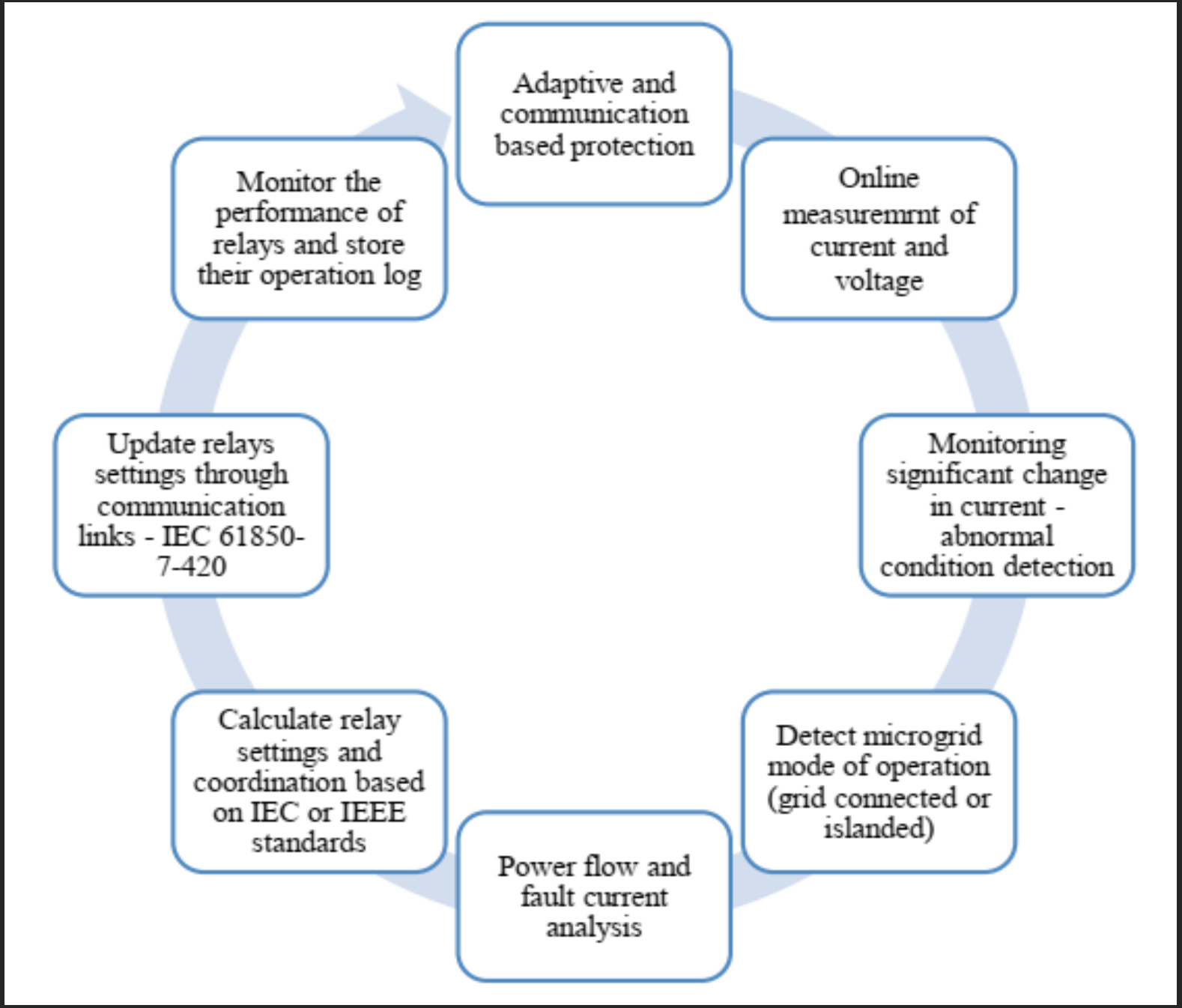
- Blinding in Protection
- False Tripping
- Unintentional DG Islanding problems
- Loss of mains
- Relay coordination issues
- varying fault currents

Need for Adaptive Protection

- System Integrity and Protection Schemes (SIPS)
- Current protection schemes in T&D systems is based on static and numerical relays.
- In transmission lines, distance protection and overcurrent protection is commonly used.
- Can modify its own relay settings in response to system conditions and the system's current running state

Why Adaptive protection?

- Rapid resolution of issues such as islanding of DGs, short circuit faults, sudden load changes etc.
- Optimized relay coordination pertaining to the changes in the network
- System restoration and security



Source: Resource Policy, Elsevier

Protection zones and Relays

Protection zone	Protective Relay
PCC	Directional overcurrent, overvoltage, under voltage, over frequency, under frequency relay
Grid side transformer	Differential and directional overcurrent
Lines and feeders	Distance, zone differential protection, directional overcurrent (backup) relay
Loads	Microprocessor-based overcurrent relay
DG units	Microprocessor-based multifunctional relay
Local DG transformer	Differential and directional overcurrent relay

Source: Switchgear and Protection by S.Rao

Signal Processing based protection scheme approaches

Methods	Fault detection features	Advantages	Limitation
WWT and Decision Tree	• WWT is used to compute Approximation, Detail, and the peak value of the WT coefficient	• Fast • Intelligent • High accuracy about accuracy is 92.1%	• Limited time resolution capability • low performance for high impedance faults • Complex due to the increased number of features
Wavelet and Data-Mining	• WT coefficient energy • Entropy • standard deviation • DT for fault detection classification	• The response time falls within 1.5 cycles and 2.5 • Enhances the dependability and reliability of PDs	• Low performance for fault classification. • A large number of features. • HIF and fault location, are not considered
DWT, KNN, and DT	• WT coefficient • DT and KNN classifier	• High accuracy for fault classification	• Fault location and HIF are not included • A large data set
DWT and DNN	• WT coefficient • Min and max value • Mean • Standard deviation • Skewness • Energy of coefficient • DNN	• Intelligent and fast fault detection, classification and phase identification • DWT and DNN • Without any communication • High accuracy	• HIF is not given. • Topology not consider • A great number of feature and data • complex • High computational burden

Source: Resource Policy, Elsevier

S-transform	• spectral energy	• Detect shunt faults and HIFs • Fast • Better anti-noise performance	• Fault location and classification are not considered
Fast Recursive Discrete Fourier Transform Fuzzy-Logic	• RMS value of fundamental phasor • Use a fuzzy logic module for system variation detection	• Efficient fault signal estimations • Smart decision- making capability and adaptive	• Fault location, classification, and HIF is not consider
Differential and Hilbert–Huang Transform (HHT)	• Spectral energy • the difference in spectral energy	• Efficient • Detect HIF • Anti-noise performance	• Costly • The fault direction is not given
Mathematical Morphology (MM) Recursive Least-Square (RLS)	• Dilation and erosion • Zero-sequence currents • RLS method	• Fast • Accurate fault localization and classification	• HIF detection are not considered • High calculation burden
WT and Shannon Entropy	• Shannon entropy • Fuzzy logic	• Fast	• Fault direction, localization, and HIF are not included
DWT	• Detail and approximation • HIF detection	• Efficient • HIF faults are identified	• Fault direction and classification is not considered • The computational burden is high
DFT and DT	• Amplitude and Phase angle • DT and SVM	• Fast and intelligent • High Performance	• Fault location, HIF and topology changes are not given

Source: Resource Policy, Elsevier

Methods	Features	Advantages	Limitations
Fuzzy interface systems (FISs)	• Teager Energy operator • Two FISs	• The response time 1/4 –1 cycle. • Fault detection/classification • HIF detection	• Fault localization and topology changes are not considered • complex in nature
Discreet Wavelet (WT) and (ANFIS)	• energy coefficient • ANFIS is used to identify the fault zone	• Fast and intelligent • Response time is 1/4 cycle	• complex computation • Large data set • Fault classification • HIF is not included • Islanded operation
DT- Fuzzy Rule	• S-transform is used to compute statistical features • Energy • Mean • Standard deviation • Entropy	• Fast	• A large number of the features • High computational burden • Fault location and HIF are not consider
Hybrid (ANN-SVM)	• Adaptive protection scheme for MGs	• Adaptive • Self-learning • Self-training • Fault location	• A large number of data sets • Complex in nature • High Computational burden and training
Fuzzy-Neuro	• Fuzzy-Neuro • Symmetrical components	• Fast • Accurate • Robust	• Network changes affect the threshold values. • Complex • Large fault data
Adaptive Fuzzy Logic	• Zero sequence component of current signals	• Fault detection, classification • Phase identification • Dynamic changes	• Communication failure • Costly due to communication system • HIF not included

Source: Resource Policy, Elsevier

AI and NIA-based protection techniques	Artificial Bee Colony Optimization (ABCO) -
	Biogeography-based Optimization (BBO)
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	Gravitational Search (GS)
	Firefly Algorithm (FA)
	Differential Evolution (DE)
	Harmony Search Algorithm (HSA)
	Artificial Neural Network (ANN)
The most successful optimization techniques	Genetic Algorithm (GA)
	Particle Swarm Optimization (PSO)
	Grey Wolf Optimization (GWO)
	Cuckoo Optimization Algorithm (COA)
	Hybrid Cuckoo Optimization Algorithm and Linear Programming (HCOA-LP)

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