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# Intelligent Control System to Detect, Classify and Reserve Power Quality in Micro Grid Through Multi-Agent System

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## Abstract

In This paper, an intelligent control system is presented which opens a new era of decentralization up to the maximum extent. It consists of three management level of agents to control with defined roles and skills. These agents interact and communicate with each other through fastest and shortest possible ways to make decisions locally and optimally. The fastest communication, interaction, and coordination, among these agents, ensure power quality (PQ) by determining, frequency and voltage of the microgrid via set points to optimize the overall operation. The intelligent control system is using Multi-agent system (MAS) Technique in grid-connected and islanded mode to detect, classify and reserve power quality in real time scenario. The top-level agents control the decisions regarding PQ of electricity Market, the middle level of agents compensate power and its quality between demand and supply while the first level of agents is ensuring power quality along with local droop control. Each independent component of the Microgrid is represented as an intelligent software agent. All intelligent physical standards are developed and implemented in intelligent MAS. The proposed control architecture and strategies are analyzed and tested in detail under various conditions for the real-time control of microgrid. The outcome of the study demonstrates the viability of the presented strategies and its control, and it also shows the excellent ability of the MAS technique for the functional operation of micro-hybrid grids.

## Keywords

Multi-Agent System, Power Quality, Intelligent Control, Microgrid

## 1. Introduction

The modern world economy is fully depended on the latest generation of smart grids, which are distinct as a power network that comprises a state of art technology within the grids capable of detecting, classifying and eliminating all types of faults with an advantage of self-healing process. The population and infrastructure of the world are increasing day by day, due to which the scalability of Centralized grids are increasing with complex management, thefts, losses, blackouts, brownouts, low system efficiency and furthermore as security the fear of natural and human-made disaster could be a huge advantage of microgrid conception. The microgrid conception may be leading to a green world system that may transform the renewable energy recourses combination to change from dependence on the fossil fuels, whereas to maintaining the balance between demand and supply [1]. In a hybrid power system, a huge investment and research analysis have been dispensed. Khan and Dihrab [2, 3] proposed a renewable source consist of a hybrid solar–wind in a grid-connected application for power generation. Hybrid solar wind power plant is modeled while using hourly solar irradiation and wind speed knowledge for two years [4]. Now a day's in industrial and public sector with the increasing numbers of solid-state switching devices, unbalance power systems, nonlinear loads, electronic components and electronic equipment's the power quality panorama is a key issue for electrical equipment and customers. Low power quality creates issues like instrumentation injury, instrumentation malfunction, less productivity, management and client's system failures lost orders and trouble in transactions [5]. To support detection and classification of power quality, many digital filters approaches are developed fordisturbances, Stockwell transform (ST) [6-8] Fourier transform (FT), wavelet transform (WT), short time Fourier transform [9-13], Hilbert transform [14, 15] and time–time transform [16], Kalman Filters [17] and symmetrical components [18, 19] are the techniques for digital signal processing which are used for the time-frequency scrutiny for detection and recognition of these non-stationary signals via extracting a range of features from the malformed patterns of these PQ disturbance signals. These range of features are utilized as input for the PQ disturbance recognition to the different pattern classifier such as support vector machine (SVM) [20], fuzzy logic (FL) [21] and artificial neural network (ANN) [22]. These techniques suffer from the extensive computations which limit the fast processing speed due to which they are unable to achieve a concentration in online applications. So there is a need for an accurate technique which supports all techniques to improve their computations time and become more fast and intelligent techniques. So that the scientist has a variety of techniques to enhance further all the technology.

Multi-agent systems (MASs) have the ability to manage the data management, and flow management. The agents are flexible, autonomous and decisive to work towards a typical goal. The benefits of multi-agents could be smart knowledge management, real-time observation, low-cost generation and consumption, quick recovery from faults, forecasting, support green world and foremost the power quality. In recent years the interest of investors and researchers are increasing in MAS techniques, and engineering applications [23] disturbance diagnosis [24, 25] system restoration [26, 27] and secondary voltage control [28] Recently through multi-agents power distribution system were also managed [29-33] Dimeas, and Hatziargyriou [34-37] have presented analysis based on real-time market-based microgrid operation through agent-based technology for managing microgrids with native intelligence of agents which give best and effective management solutions. McArthur et al. [38, 39] elaborated the technical issues, approaches, and concepts with prospective standards of the multi-agent system for in applications of power generation and standard tools, style methodology and supporting technologies that would be included in realization for MAS in Power engineering. In [40-42], the applications of MAS in power engineering are tinted. In this paper, the control & management of power quality detection, classification and to reserve power quality is proposed in real time scenario of a hybrid smart grid through an intelligent MAS architecture. Logenthiran et al. [43] presented MG real-time operation through real-time simulator which primarily focused on the real-time power management, while Thillainathan Logenthiran [44] presented real-time control MG from an electronic power perspective and implementation issues were discussed. Hybrid smart grids (PV and wind turbines) are non-dispatchable sources, and their outputs are mainly depending on weather conditions. To achieve the desired power quality in the hybrid smart grid, control strategies are developed for all major components represented as autonomous intelligent agents. All agents can take decisions according to the real situations and communicate with each other within the smart grid. The MAS technology is facilitated through cooperative control and distributed architecture facility. Java Agent Development Framework (JADE) supports the MAS where it is implemented [45-48], intelligent physical agent (FIPA) foundation is an open source [49-52] complaint platform for multi-agents. Microgrid was modeled for real-time in MATLAB.

The arrangement is given as below. Section II explains the main components and its configuration of a hybrid microgrid. In the section-II, I the proposed control within the structural design is proposed in detail. While in section-IV the MAS implementation is presented. The real-time strategies and its implementation are discussed in section V, and in section VI the outcome and discussion are given, and as a final point in section VII, the conclusion is presented.

## 2. Multi-Agent Based Hybrid Micro-Grid System

This manuscript considers a smart hybrid micro-grid which includes distributed renewable energy recourses with a facility of energy storage system as shown in Figure 1. In Smart hybrid micro-grid, energy recourses have their character in the schematic configuration, which is controlled by separate agents. The multi-agent approach is the most suitable modeling for distributed energy resources which needs a level of independence and decision making due to their different types and level of situations. If hierarchy defines the roles and responsibilities of multi-agents, furthermore the failures of the system can be tolerated by sharing responsibilities among the different agents. The system operational efficiency on demand can be achieved through many agents' interaction and synchronization in a parallel calculation. In the MAS agents can be easily added and deleted. Hence, scalability parallelism and robustness are the fundamental benefits of MAS.

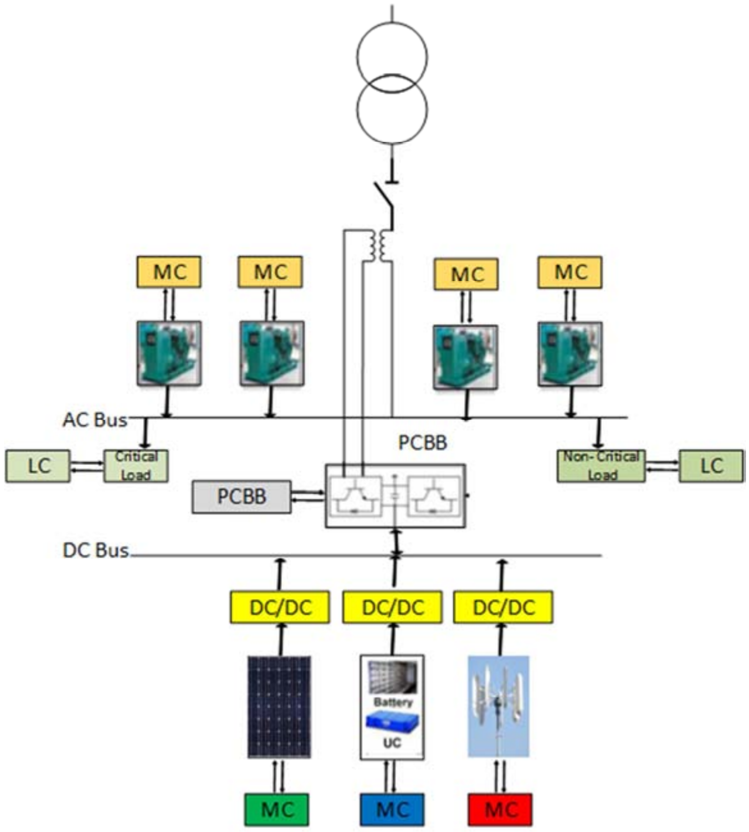


***Figure 1.*** *Block Diagram of the Proposed System.*

The Scientist and researchers are working so hard to improve the power quality, but now they reach to a transition stage where names along with methods are changing drastically to improve the Power Quality, but results are still same. So it's a time to focus on the Management control of the system to improve detection, classification, and reserve power quality within the system. In this aspect communication and coordination plays a vital role in all management control levels for instruments along with their roles & skills. In power quality, the most critical challenge is the timing to detect and classify within possible shortest time and further take necessary measures automatically in real time. In all these scenarios the understanding of information exchange level and coordination are foremost essential as shown in Figure 2.


***Figure 2.*** *Different level of Agents Communication.*

In this paper, many agents are communicating and coordinating with each other, but the main challenge within the multiagents-based microgrid is the communication in neighboring agents to discover the global information. In distributed setting average consensus theorem is used to discover global information based on local information of agents [53]. Let's suppose that $Z_a \epsilon$ A which represent the Agent "a" state variable, the disseminated information dispensation of agent "a" can be expressed as:

$$z_a^{m+1}(V) = Z_a^m(V) + \sum_{b \in P_a} \gamma_{ab} \left[Z_a^m(V) - Z_b^m(V)\right] \quad (1)$$

The total number of agents are denoted by "n," Where a=1, 2, 3,….n, b=1, 2, 3….n; If agents "a" and agent "b" are linked through a communication line, then the information shared by agent "a" at iteration m and m+1 are $Z_a^m$ and $Z_a^{m+1}$ respectively, while m is the discrete time index. The information exchange coefficient between neighboring agents "a" and "b" is$\gamma_{ab}$. Multiagents-based Microgrid distributed information processing can be articulated as:

$$Z^{m+1}(V) = Z^m(V) + \text{Y x} Z^m(V) = \text{L+Y} Z^m(V) = Y^* \text{x } Z^m(V) \quad (2)$$

The coefficients are premeditated subject to the communication topologies where the information matrix is$Z^m$, while identity matrix is the L and the updating matrix is the$Y^*$which satisfy the restriction/limitations$\sum_a \gamma_{ab}$ and $\sum_b \gamma_{ab}$. A positive definite lyapunove function is defined for stability analysis in equation-3 which also adapt to changes in information processing for communication topologies.

$$N^m = (Z^m)^U Z^m$$

$$\Delta N^m = [(Z^m)^U \, (Y^U \text{Y-L} Z^m] < 0 \quad (3)$$

When the changes occur in the communication topologies, the corresponding adaptive method is presented as

$$\gamma_{ab} = \begin{cases} \frac{2-\alpha}{S_a+S_b} \ \text{b} \in P_a \\ 1 - \sum_{b \in P_a} \frac{2-\alpha}{S_a+S_b} \ \text{b} = \text{a} \\ 0 \ \text{b} \neq P_a, \text{b} \neq \text{a} \end{cases} \quad (4)$$

"a" and "b" are neighborhood agents and $S_a$ and$S_b$ are the numbers of agents consequently. The convergence constant is $\alpha$ which is bound between 0 and 2. So when neighborhood changes than each agent must update its corresponding weight locally. The equation-3 lvapunove function can be expressed as:

If $\gamma_{ab} = \frac{2-\alpha}{S_a+S_b}$, b≠a and 0<$\alpha$<2

Then

$$\Delta N^m = [(Z^m)^U \, (Y^U \text{Y-L}) Z^m]$$

$$< -\sum_{a=1}^{S}\sum_{b=1}^{S}[(\gamma_{ab} - \gamma_{ab}{}^2)\,(Z_b^k - Z_a^k)^2] + \frac{1}{2}\sum_{a=1}^{S}\sum_{b=1}^{S}[(S_a - S_b - 2)\,\gamma_{ab}{}^2 (Z_b^k - Z_a^k)^2] \quad (5)$$

$$< -\sum_{a=1}^{S}\sum_{b=1}^{S}[(\frac{2-(S_a-S_b)\gamma_{ab}}{2})\gamma_{ab}(Z_b^k - Z_a^k)^2$$

$$< -\sum_{a=1}^{S}\sum_{b=1}^{S}[\frac{\alpha(2-\alpha)}{2(S_a-S_b)}(Z_b^k - Z_a^k)^2]$$

$$< 0$$

The equation-5 satisfies equation-3 which clearly shows the stable information exchange while at the time of convergence the value of $Z_a$ will converge to the similar average value as shown in equation-6

$$Z_Y = \frac{1}{S}\sum_a z_a^0 \,(1, \dots 1, \dots 1)^U \quad (6)$$

The average-consensus theorem based information processing average values is achieved via $Z_Y$ while at an initial load value is$z_a^0$. It's important to note that all agents continue updating them via information processing until $(z_a^m - z_b^m)$ becomes zero as per equation-2. This action to reach equilibrium may take long tima e, thus in equation-7 a termination criteria is defined when $(z_a^m - z_b^m)$ reaches near to zero.

$$\sum_{q=m-x}^{m} \left|(Z_b^q - Z_a^{q-1}\right| < \sigma \quad (7)$$

The accuracy and convergence speed both depend on the$\sigma$; it's a real number near to zero where m is the integer that indicates the number of iterations. At the arrival of average consensus, each agent terminates its information processing. It's important that to know that all discovered information of the global information by the distributed information processing is the average value of all agents that participate in global information processing to get global information. Let's suppose that for each agent unique index number is "a" while by the distributed information processing each agent can achieve the total number S which is as follow:

$$P_{Ya} = \frac{a}{S} \Rightarrow \text{s} = \text{a}/P_{Ya} = \text{a}/\frac{a}{S} \quad (8)$$

When in the multi-agent system new agent is added it is allotted with an S number. Index "a" is the average value of $P_Y$which is identified by ath agent. Global information is the number S which reflects the participation of an agent in the information processing; this prerequisite is the key factor of plug and play operation. In particular when new agent is added or plug out so marked as (s+1) or (s-1) thus the $P_{Ya}$discovered by the ath agent changes to [a/(s+1)] or [a/(s-1)] respectively. The exclusive indexes of the on hand agents do not need to change the information discovery, in this case only,, the neighbors need to update the local information and by this way all, agents come to know about the number S and communication topologies changes locally and adapted. In the global discovery information every, agent the updates itself with an information updating process while according to the consensus theory exchange process of the overall information is based on discrete time linear system which is represented as

$$Z_{m+1} = GZ_m \quad (9)$$

Which shows that the discover information $Z_m$ and $Z_{m+1}$ are the vectors at the m and m+1 iterations while G is multi-agent network graph of the Laplacian matrix [54]

In a multi-agent system, every agent maintains a value for every possible action which is denoted by 'B,' in performing actions these values provide the useful estimation with every step and to update neighbors and itself accordingly to the reward receiving for the action this learning algorithm is given as

$$B^{m+1}(d_1 \dots d_i \dots d_n) = (1-\gamma)B^m(d_1 \dots d_i \dots d_n) + \gamma.[x^m + \beta max B^m(d_1 \dots d_i \dots d_n)] \quad (10)$$

In this paper, the distributed Q-learning algorithm is implemented which is described in [55] and [56]. The reason behind its implementation is good efficiency regarding required memory. The distributed Q-learning algorithm updating rule is given as:

$$\delta \leftarrow x^m - B_i^m(d_i)$$

$$B_i^{m+1}(d_i) \leftarrow \begin{cases} B_i^m(d_i) + \gamma\delta if \delta > 0 \\ B_i^m(d_i) + \alpha\delta \text{else} \end{cases} \quad (11)$$

In this multi-agent system, the balance between exploration and exploitation is considered to be the key importance during RL implementation whereas the two different learning rates are$\gamma$ and $\alpha$. In both exploitation and exploration, the agents suffers in a way that excessive exploration consumes much time which ultimately degrades the performance of the Q-learning algorithm while the causes of agents failure are pure exploitation in finding the global optimal solutions. As per SA (simulated annealing) algorithm on the basis of metropolis principal, the shifting from the present act means "randomly chosen action". $d_{ri}^m$to thus far preeminent act means "action with the utmost" $d_{bi}^m$ is defined as:

$$d_i^m = \begin{cases} d_{bi}^m, exp^{(\frac{B(d_{ri}) - B(d_{bi})}{U^m})} < \in \\ d_{bi}^m, \text{otherwise} \end{cases} \quad (12)$$

Agent a chooses the control action $d_{i,}^m$ while $\epsilon(0 < \epsilon < 1)$ is a set of smaller numbers, while the size of U encourages the exploitation and exploration the bigger encourages exploration and smaller encourages exploitation. This value of U decreases in a process of exploitation takes over from exploration in selected lower confines has been attained. The proposed method in [56] during learning can significantly decrease the probability of exploration$\epsilon$ in comparison to the $\varepsilon$-greedy method. At the start a large value can be set for U which decrease with each learning step subject to $U_{m+1} = p \times U_m$ with $0 < p < 1$. It will improve agent ability in term of new knowledge learning but also avoid recital dreadful conditions while using constant$\epsilon$, as demonstrated through experiment in [56]

## 2.1. Micro Sources

The distributed energy resources in microgrid consist of two the PV system and Wind Turbine both are connected through the best possible electronics interfaces. PV system and Wind system both generate power from solar irradiation and wind speed simultaneously which continuously varies with time. The Available models of PV and Wind are used in the microgrid modeling. In respect to create the test case, real irradiance and temperature for PV system and wind and Gust for wind system are used, these distributed power recourses have personal MCs.

## 2.2. Composite Energy Storage System

In the hybrid smart grids, the energy storage elements are performing the key roles in load side demands due to the variation [57]. CESS (Composite energy storage system) is designed to sustain fluctuations of the load demand, with the help of high energy storage component like batters and high power density storage elements like ultra-capacitor. In this manuscript a real-time CESS model is attached with DC bus bar to control the voltage, Dual active bridge (DAB) is used for CESS in a power interface. Transfer of power is accomplished by shifting voltage across the main & secondary sides in the high-frequency transform. The operating principal's detail and models are presented in [58] - [59]. The average output can be written as:

$$I_o = \frac{T_s n V_{in}}{2L}(d - d^2) \quad (13)$$

$I_o$ is the output current of the secondary side,$V_{in}$is the input voltage of the primary side, d is controlled phase shift, while coupling inductance is L and switching time is $T_s$ . Furthermore, the turn ratio is denoted by n of transfothe rmer. $P_o$ is the output which can be written as:

$$P_o = \frac{n V_{in} V_o T_s}{2L}(d - d^2) \quad (14)$$

$$P_o = V_o I_o \quad (15)$$

$$P_o = \eta P_{in} \quad (16)$$

$P_{in}$ is the input power of the primary side, The $P_o$ $is$the output power on the secondary side, $\eta$ is the Conversion efficiency and $V_o$ $is\ the\ S$ econdary side terminal voltage, CESS can be distinguish by the Power rating, access ramp rate of power and energy capability, in lumped model of an energy storages. On the current integration the SOC (State of charge) can be calculated for CESS which can be written as:

$$\Delta SOC = \frac{\Delta Q}{Q} = \frac{\int i_{ES} d_t}{Q} \quad (17)$$

Where, $i_{ES}$ is current drawn from Energy storage and Q is the rated capacity

### 2.3. Power Control Systems

#### 2.3.1. Control System of Photo-Voltaic

The maximum power point (MPP) of PV module depends on the solar irradiance, which is changing continuously with time. Therefore the output curve of cell temperature and solar irradiance is nonlinear. In this paper Perturb and observe (P&O) algorithm will be used to keep PV model on MPP. Measurement of current (I_pv) and Voltage (V_pv) are required by the P&O algorithm, while the converter with input current control (I_ref) is deployed to step-up the photo-voltaic voltage to higher DC Voltage and reduces the switching harmonics. To balance the power, the P&O algorithm which is also known as Maximum power point tracker (MPPT) of the PV system and PEC (electric power converters) is connected with an automatic feedback controller which maintain DC constant under various conditions

#### 2.3.2. Wind Turbine Control System

Wind Turbine Induction Generator Output power experience variations in amplitude & frequency due to high deviation in wind speed. Double-bridge rectifier is used as a controllable ac/dc converter to smoothen the output power the of the wind turbine before supplying to other equipment. Double-bridge rectifier control output voltage, furthermore on the source side it has less harmonic distortion effects which can be caused by tuning the firing angle ($\alpha$) and narrowing commutation periods of the 12-pulse synchronized PWM generator to obtain six input ports with suitable phase angles for the double-bridge rectifier a three phases two windings transformers are used. Discrete PI controller controls the firing angle ($\alpha$).

#### 2.3.3. CESS Control System

To control the DC bus voltage and the power flow a bi-directional Dc-Dc converter is required to interface Dc bus, and CESS bi-directional power transform can be accomplished by phase changing of main & secondary side bridge voltages. High-frequency transformer can perform the seclusion among Energy storage and load. To facilitate the functions like grid-connected inverter, ac/dc bus inverter and active filter PCBB (Power converter building block) is placed in the system. Power converters and switching agent models are explained in [60] - [61].

## 3. Architecture of the Proposed Control

The future smart grid looks for decentralizing control architecture, and many researchers are busy to propose different types of a decentralized control architecture for diverse nature of power system and validate them through many case studies. In this paper, a 3 level control and management system with defined roles and skills are proposed to achieve Fast & Reliable system with three basic goals which are Smart, Secure and Safe. This proposed control and management system is designed to detect, classify and reserve Power Quality in real-time control of microgrid. The proposed control and management system concepts are designed according to overall system performance and system requirements.

### 3.1. Management Levels of Agent to Control

#### 3.1.1. The Top Level of Agents to Control

These Top level agent's/Top agents are also known as executives. These agents can be a human or machine. Top agents do not a direct hour to hour activities. These agents are responsible for entire system especially overseeing and controlling the Power Quality these agents hold power to stop the system due to Power quality problems. They develop the direction of the business and make decisions to develop goals such as long and short-term scheduling (Monthly, weekly or daily ahead planner), company policies and strategic plans such as generation scheduling, demand side management, load forecasting. Top level agents play a significant role; they set goals for the grid system and direct the middle-level agents to achieve the desired goals. The entirety of the firm is directly affected by the top level agents. They share knowledge through a shared information system as shown in Figure 3.

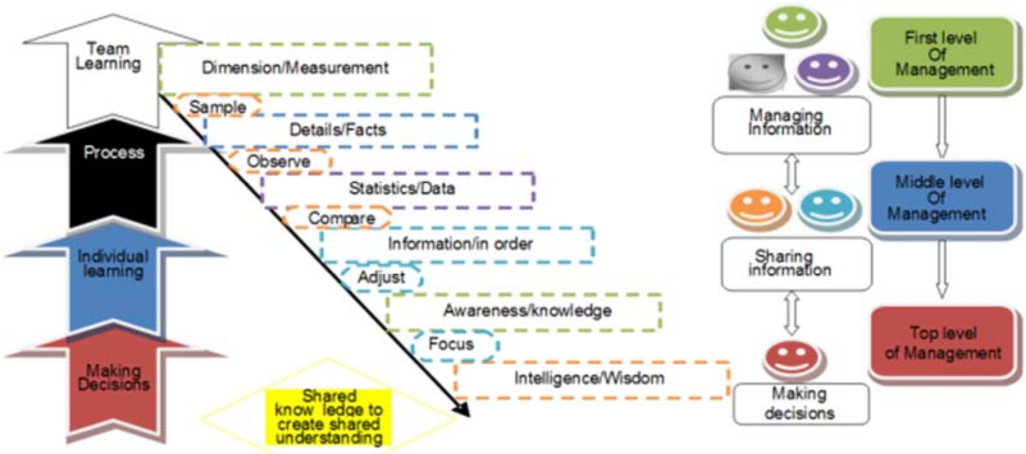


***Figure 3.*** *MAS share knowledge process.*

#### 3.1.2. The Middle Level of Agents to Control

Middle-level agents or middle agents are also called managers. These agents are responsible to the Top level agents for their section function especially ensuring Power Quality. Middle-level agents can stop some sections due to power quality problems. Middle-level agents are responsible for compensating power unevenness among the load and power supply. It's also accountable for the Control actions when frequency variations take place. These level of agents produce new set points by toting up the intended power to the original allocated power, it brings the system to the reference frequency and among the recourses shares the power optimally. These agent's response is quicker to first level agents than the top level as they work more time to directional and organizational functions than top-level agents. Middle-level agents execute plans to achieve the Top level management objectives in conformance with the company policy. Monitor group level performance indicators, resolve problems through system supporting cooperative behavior, implementing effective group work through an information system, providing guidance and discussing information and policies from first level agents to level agents and vice versa. Jobs of middle-level agents are very wide in terms of accountability depends on the mass of architecture of the system. Middle agents may control a large group of agents or supervise a small group of agents. They share knowledge to create shared understanding Figure 3.

#### 3.1.3. The First Level of Agents to Control

First level agents or first agents are also called supervisors. First level agents are accountable for day to day running of inline machines or equipment which actually offer service or produce. These agents are assigning a task to the equipment, guiding and supervising equipment on a day to day activities and ensuring quantity and quality of the concerned subject making recommendation and suggestion to the system. These agents update and forward performance feedback and also up channeling the equipment problems. The system totally depends on their first line agent's coordination and efficiency. They understand to implement shared knowledge and inform back.

### 3.2. Management Role of Agents to Control

#### 3.2.1. Decisional Roles of an Agent

The utilization of resources and its planning are the decisional roles of an agent to plan. Top level agents usually hold such roles, but middle agents and first level agents can be given some of the abilities to make disturbance handler can handle some decisions like unanticipated problems from the internal and external environment. e.g., First line agents may correct faults in their concerned section or second level agents may attempt to report a theft on lines aftermath. Top level agents are more likely to deal with emerging crises or negotiation with suppliers or distributors regarding supply and demand

#### 3.2.2. Interpersonal Roles of an Agent

Interpersonal roles require agents to supervise and direct machines/equipment in the system. Usually middle manager top is the figurehead. These agents may converse prospective organizational objectives and instructions and guidelines to subordinates to makes decisions, and organize equipment support. Agents should be cooperative at the systems all levels; frequently first-level agents look to top-level agent's management for collaboration, assistance and the best updated available resources. In the role of relationship, an agent must coordinate in the different work units to the work of others agents by establishing alliances in between sharing work resources. The key to Middle-level agent's tasks is cooperation for a long period to maintain a successful working relationship. This role is very critical to complete tasks with other agents in important aspects.

#### 3.2.3. Informational Roles of an Agent

Informational roles agents receive and broadcast information within the system and out of the system as a specific task or as a general task. These roles have enhanced spectacularly as expertise in technology changed. To improve the performance, all the performances are evaluating the monitors for the counteractive measures. They are the close observers for any changes which may affect in organizational or individual performances. At all levels, the monitoring process occurs while at high agent's level they monitor the external threats to the or from the external environment. The function of disseminator requires communicating the information of changes for the purpose that agents recover that machines/ equipment from affecting them and the system. The information runs from the top down and down up at each level of Agents to disseminate information in the direction of the organization. Major announcements are made by the spokes agents such as an alteration in strategic direction, is probably to be a top agent while more routine information is provided by an agent at any level of a system.

### 3.3. Management Skills of Agents to Control

Apart from all system levels, agents should have five critical skills:

#### 3.3.1. Conceptual Skills of an Agent

Conceptual skill is an agent's ability to see his specific task/section/system as a complete entity. Through these skills, agents understand how the system works in a competitive environment and fits units to work together in the system perfectly. Conceptual skills are important most for top agents, to monitor "the big depiction" which can have a consequence on the accomplishment of the organizational goal. while, for middle-level agents and first line agent's conceptual skill are also necessary for coordination, feedback and system delivery in perfect order

#### 3.3.2. Technical Skills of an Agent

The Technical skill of an agent includes understanding and signifying task in a specific task place with proficiency.

Technical skills such as using system application; follow protocols, communication, operating a part of equipment/machinery. These technical skills change with the level of management except crises & communication skills. First-level agents are usually engaged in the real operations of the system; they must understand that how production and service occur in the system in the array to express and work with inline agents. Additionally, in scheduling agents, the first-line managers need skill and arranging a day to day task on the priority of top management agents. Middle-level agents use additional technical skills linked to organizing and planning; top agents need the skill to be aware of the multifarious workings of the system for the system.

### 3.3.3. Diagnostic Skills of an Agent

The Diagnostic skill of an agent is used to detect the problems than classify that problems and immediately decide on a cure to execute a solution. Diagnostic skills also involve technical, conceptual, political and interpersonal. Such as, to establish the root of a dilemma, an agent may require to converse with another system agents to be aware of a multiplicity of informational credentials Figure 3. The utilization of diagnostic skill across the agents management levels is difference principally due to the nature of troubles which should be required to address at every level of agents. Such as, first-level agents may deal mainly with issues of faults, and it's counteractive, such as determining why a particular equipment routine is deteriorating and how to recover it. Middle agents are possibly dealing with related issues in larger work units, for example, a power quality, of production and functions set & reset in grid connected and islanded modes. Top agents identify organization-wide troubles and may tackle issues such as tactical spots, the perspective of outsourcing activities.

### 3.3.4. Interpersonal Skills of an Agent

The Interpersonal skill of an agent involves agent's dealings, or the agent's capability to interact efficiently with system agents in synchronization. A critical part of the interpersonal skill is an interaction while strong communication. At all levels of agent management, this skill is very much critical as shown in Figure 4.

### 3.3.5. Political skills of an Agent

The Political skill of an agent involves the right of power to utilize in critical situation and averting other agents from each other's power. To accomplish organizational targets agents, use their powers and resources. Agents with political skill can frequently reach targets with fewer endeavors than others who are deficient in political skill. Agents require political skill at all levels to avoid negligence. Top agents may find that in order to operate successfully they need higher levels of political skill in their environments while cooperating with suppliers, competitors, shareholders, customers, and government.

## 4. Implementation of Multi-Agent System

The Hybrid microgrid considered in this paper has several types of agents like reactive, cognitive, intentional / BDI adaptive and communicative in all three management levels with defined skills and roles. The hybrid micro grid consist of many components which represent by an independent choice making agents such as, Grid agent, CB agent, PCC agent, Makeup agent, Power Quality Control agent, Smart Grid Controller (SGC), Start agent, Power-Source agent, PCBB agent, Bus agent, Inverter agent, Generation agent, Storage agent, Cess agent, Photo-voltaic agent (PVAG), Battery agent (BAG), Wind Turbine agent (WTAG), Distributed Energy Resources (DER) agent, Facilitator agent, Micro Grid agent, Controller agent, Database agent, Logic Network agent, Online Learning agent, Power Quality Detect \& Classification agent, Corrective Measure agent, Control agent, User agent, Diesel Generator Agent (DGAG) Load Agent (LAG), Consumer agent, Substation Agent, Micro-Hydro Turbine agent (MHTAG). Every Agent by providing feedback communicates with everyone and also monitor and control corresponding equipment. Furthermore, every agent makes decisions in line with his skills and roles subject to management level locally.

***Table 1.*** *Multi-agents decision level, types, and skills.*

| Name of Agent | Management | Roles of Agent | | |
|---|---|---|---|---|
| | | Decisional role | Interpersonal role | Informational role |
| Grid agent | Top Level Agent | *** | ** | *** |
| CB agent | First Level Agent | * | * | *** |
| PCC agent | Middle Level Agent | ** | *** | *** |
| Makeup agent | First Level Agent | * | * | *** |
| Power Quality Control agent | Middle Level Agent | ** | *** | *** |
| Smart Grid Controller (SGC) | Middle Level Agent | ** | *** | *** |
| Start agent | First Level Agent | * | * | *** |
| Power-Source agent | First Level Agent | * | * | *** |
| PCBB agent | Middle Level Agent | ** | *** | *** |
| Bus agent | First Level Agent | * | * | *** |
| Inverter agent | First Level Agent | * | * | *** |
| Generation agent | First Level Agent | * | * | *** |
| Storage agent | First Level Agent | * | * | *** |
| CESS agent | First Level Agent | * | * | *** |

| Name of Agent | Management | Roles of Agent | | |
|---|---|---|---|---|
| | | Decisional role | Interpersonal role | Informational role |
| Photo-Voltaic agent (PVAG) | First Level Agent | * | * | *** |
| Battery agent (BAG) | First Level Agent | * | * | *** |
| Wind Turbine agent (WTAG) | First Level Agent | * | * | *** |
| Distributed Energy Resources (DER) agent | Middle Level Agent | ** | *** | *** |
| Facilitator agent | Middle Level Agent | ** | *** | *** |
| Micro Grid agent | Middle Level Agent | ** | ** | *** |
| Controller agent | Top Level Agent | *** | *** | *** |
| Database agent | Middle Level Agent | ** | *** | *** |
| Logic Network agent | First Level Agent | * | * | *** |
| Online Learning agent | First Level Agent | * | * | *** |
| Power Quality Detect & Classification agent | First Level Agent | * | * | *** |
| Corrective Measure agent | Middle Level Agent | ** | *** | *** |
| Control agent | Middle Level Agent | ** | *** | *** |
| User agent | First Level Agent | * | * | *** |
| Load Agent (LAG) | First Level Agent | * | * | *** |
| Consumer agent | First Level Agent | * | * | *** |
| Substation Agent | Top Level Agent | *** | ** | *** |
| Micro-Hydro Turbine agent (MHTAG) | First Level Agent | * | * | *** |
| Diesel Generator Agent (DGAG) | First Level Agent | * | * | *** |

***Table 2.*** *Continued.*

| Name of Agent | Skills of Agent | | | | | Type of Agent |
|---|---|---|---|---|---|---|
| | Conceptual skill | Technical skill | Diagnostic skill | Interpersonal skill | Political skills | |
| Grid agent | *** | *** | *** | *** | *** | Learning agent |
| CB agent | * | *** | *** | *** | * | Model-based reflex agent |
| PCC agent | ** | *** | *** | *** | ** | Learning agent |
| Makeup agent | * | *** | *** | *** | * | Model-based reflex agent |
| Power Quality Control agent | ** | *** | *** | *** | ** | Learning agent |
| Smart Grid Controller (SGC) | ** | *** | *** | *** | ** | Learning agent |
| Start agent | * | *** | *** | *** | * | Simple reflex agent |
| Power-Source agent | * | *** | *** | *** | * | Utility based agent |
| PCBB agent | ** | *** | *** | *** | ** | Learning agent |
| Bus agent | * | *** | *** | *** | * | Utility based agent |
| Inverter agent | * | *** | *** | *** | * | Utility based agent |
| Generation agent | * | *** | *** | *** | * | Model-based reflex agent |
| Storage agent | * | *** | *** | *** | * | Utility based agent |
| CESS agent | * | *** | *** | *** | * | Utility based agent |
| Photo-Voltaic agent (PVAG) | * | *** | *** | *** | * | Goal based agent |
| Battery agent (BAG) | * | *** | *** | *** | * | Goal based agent |
| Wind Turbine agent (WTAG) | * | *** | *** | *** | * | Goal based agent |
| Distributed Energy Resources (DER) agent | ** | *** | *** | *** | ** | Learning agent |
| Facilitator agent | ** | *** | *** | *** | ** | Learning agent |
| Micro Grid agent | ** | *** | *** | *** | ** | Learning agent |
| Controller agent | *** | *** | *** | *** | *** | Learning agent |
| Database agent | ** | *** | *** | *** | ** | Learning agent |
| Logic Network agent | * | *** | *** | *** | * | Goal based agent |
| Online Learning agent | * | *** | *** | *** | * | Goal based agent |
| Power Quality Detect & Classification agent | * | *** | *** | *** | * | Goal based agent |
| Corrective Measure agent | ** | *** | *** | *** | ** | Learning agent |
| Control agent | ** | *** | *** | *** | ** | Learning agent |
| User agent | * | *** | *** | *** | * | Simple reflex agent |
| Load Agent (LAG) | * | *** | *** | *** | * | Simple reflex agent |
| Consumer agent | * | *** | *** | *** | * | Simple reflex agent |
| Substation Agent | *** | *** | *** | *** | *** | Learning agent |
| Micro-Hydro Turbine agent (MHTAG) | * | *** | *** | *** | * | Goal based agent |
| Diesel Generator Agent (DGAG) | * | *** | *** | *** | * | Goal based agent |

JADE is an open source multi-agent development framework with a directory facilitator (DF) service. DF services allow agents to list their queries & services that what he and other agents offer. JADE supports an asynchronous agent-programming model in java language with the facility of communication among agents through similar or unusual platforms, security, mobility and lots of other facilities with its enormous assets and libraries. Standards and specifications are managed by JADE according to IEEE and FIPA which simplifies the implementation of the agent systems through a middleware. JADE also facilitate user-defined ontology with own terminology and expressions along with semantics for the contents of communication exchange between the agents. To employ the framework to manage the MAS it is essential to describe each agent with his utility subject to his roles, skills and characteristics goals. Responsibilities and objectives of each agent are discussed in the subsection

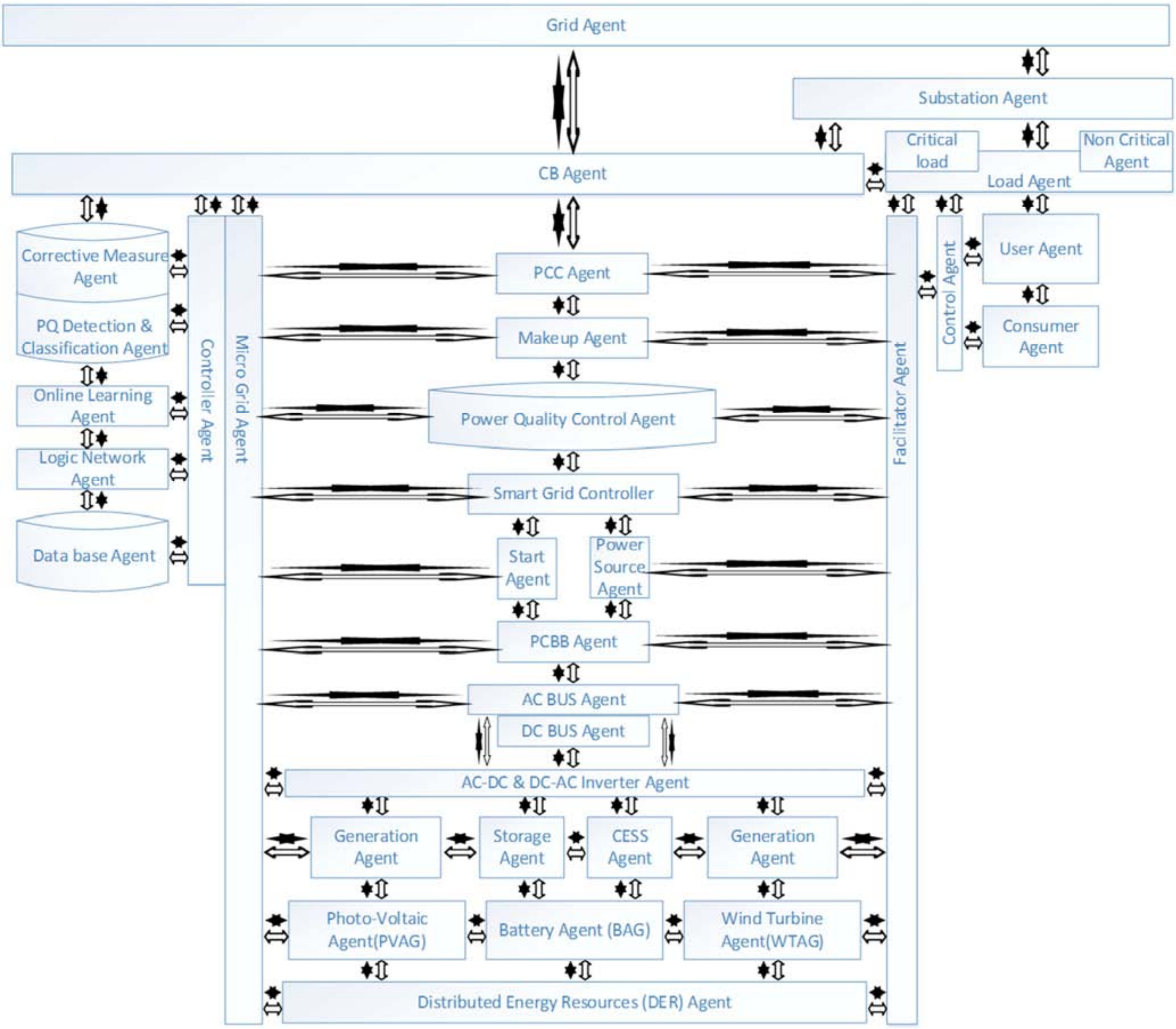


***Figure 4.*** *Agents Collaborative Diagram.*

### 4.1. Agent Specifications

*Grid Agent*

Grid Agent is accountable for power import & export from or to the main grid to the Market operation negotiated by Top level, while the Second task is monitoring in a grid-connected mode.

*CB Agent*

This agent (circuit breaker) is working as a switch; it connects or disconnects the system based on control command. It interacts with the all breakers in the micro-grid.

*PCC Agent*

The responsibility of PCC agents is to scrutinize the grid voltage, frequency, and phase angle; furthermore, it informs other agents about the changes in the status of the microgrid.

*Makeup Agent*

It's a special agent which facilitate the power to bring into existence by shaping, modifying, or putting together an upgrade to the required results as per user's demand

*Power Quality control (PQC) Agent*

The PQC agent is a special kind of agent which monitors the incoming & outgoing power quality in all aspect.

*Smart Grid Controller (SGC) Agent*

SGC has two main function one it makes operation decision and its second function is to control the timing of negotiation. The purpose of this agent is unique because it contains information's regarding resource availability and its allocation policy, weather forecast and negotiation process of the multi-agent system, etc.

*Start Agent*

The agent's communication process begins by start agent in the multi-agent system by sending controller agent a signal.

*Power-Source Agent*

It is responsible for ON/OFF status of the corresponding Micro sources producing power. It's also responsible for controlling, negotiating and monitoring of micro sources.

*PCBB Agent*

Grid agent set reference points for PCBB to make decisions regarding power to withdraw or deliver to grid station. It monitors Power level, Current, and Voltage of Microgrid.

*Bus Agent*

In this proposed Model there are two bus agent's AC & DC, and each function is same to monitor the voltage phase angle, voltage magnitude that these do not exceed its limits

*Inverter Agent*

As DC source produces power it monitors the process of change from Direct Current to Alternating Current or vice versa. It also monitors the input voltage and output voltage with a desired frequency and overall power handling.

*Generation Agent*

The Generation agent controls the Flow of energy as in Microgrids renewable energy is usually generated from Microturbines, Solar, Wind, biomass, and others. Renewable energy is a great source, but it has many flaws such as they required additional hardware for integration in Microgrids, secondly due to fluctuation and intermittent of energy output can impact component performance, grid voltage and grid frequencies which ultimately causing instability and interruption in services of power generation system for customers. This agent supply COs which are connected to DG directly with the energy if they need it then they store it or sent it to the grid. If none option is available than the agent decides to stop or decrease the generation of energy

*CESS Agent*

This agent deals with SOC level when it's low based on local measured information it requests power from Power grid agent and Micro source agent. CESS determines at every instant how much energy is needed to supply or store.

*Storage Agent*

The Storage Agent manages the flow of energy through ES type entities. In micro-grid using ES's Resources can solve Intermittence problems. It saves a lot of energy from being wasted. This agent when detects high or low energy in micro-grid, then it initiates by absorbing or releasing energy to keep the load at a reasonable threshold in the grid.

*Photo-Voltaic Agent (PVAG)*

The PVAG Agent deals with SGC regarding power sale, it sends request message which includes the price and quantity of power for sale on availability.

*Battery Agent (BAG)*

The BAG Agent deals with SGC regarding power sale, it sends request message which includes the price and quantity of power for sale on availability, and also receive messages from SGC regarding purchase or sale of the Electric power. BAG agent facilitates the battery by measuring the amount of charge at every instant if it needs to charge from grid or discharge when PVAG is not available. BAG; installed at battery center, it monitors the capacity, amount of charge, and the status (charge/discharge).

*Wind Turbine Agent (WTAG)*

The WTAG Agent deals with SGC regarding power sale, it sends request message which includes the price and quantity of power for sale on availability.

*Distributed Energy Resources (DER) Agent*

The DER agents in this model controls and monitor the power level and control over Connect /disconnect Status of Wind Turbine, Photo Voltaic, storage agent, Inverter. In the IDAPS the DER agent is dealing with the control of all Energy resources.

*Facilitator Agent*

This Agent is unique and special. It facilitates all problems in the MicroGrid because it links to all other agents. A facilitator agent monitors current load from time to time in the Microgrid to avoid thresholds and take necessary actions if they persist. If any problem occurs in the MicroGrid, the facilitator agent uses all possible approaches within his domain and decides after analyzing the situation. The Facilitator agent communicates with all other agents for a solution to accept or it proposes by itself, or it may involve other entities of high-level domains to solve or intervene unless the problem persists.

*Micro Grid Agent*

The Microgrid agent keeps track of each agent and serves as a data access spot. It shares data/messages among the agents. It represents the micro-grid model in a multi-agent system.

*Controller Agent*

This agent is known as "Brain" of the multi-agent system. It monitors all agents and their functionalities and working. It keeps information about all DER agents regarding Voltage and power. The controller agent of this system can be connected to other system controller agent if interested that IDAP is connected to the Smart grid or Micro Grid.

*Database Agent*

Data Base agent is known as Memory of the MAS. It has all location and accesses addresses of agents. Controller agents keep track with the help of Database agent because of information names and functionalities of agents

*Logic network Agent*

This agent is smart and predicts things with logic. It facilitates the controller and facilitator agent through different logic types such as Formal Logic, Informal logic, symbolic logic, Mathematical Logic, Universal Logic, Computational Logic, Predicate Logic, Non-Classical Logic and neural Logics to solve different issues in the micro-Grid.

*On-line learning Agent*

This agent facilitates all management level agents to learn online with all possible updated solutions in concerned libraries. This agent provides classified libraries as per directions of the Top Management Agents level

*Power Quality Detect \ & Classification Agent*

This Agent is the important most agent in the MAS when the Power Quality agent detect some anomalies in the power it sends immediately message to this agent to detect the cause and classify the power quality for the Corrective measure as per standards.

*Corrective Measure Agent (CMA)*

When the CMA receives a message about error/fault from facilitator agents or controller agent or PQ\&DC agents it immediately provides the cause and possible reasons and sources from Database and suggests the quickest possible solution among all solutions. Furthermore, it facilitates the Facilitator agent with the permission of higher level management to take necessary actions. Its advantage is that if any problems occur in the system at a time, it will prioritize the level of problem and its solution one after other.

*Control Agent*

Control Agent communicates with facilitator agents about the consumers, users and substation day to day issues and solves it with the help of Controller agent from the Database and facilitates them till issue solves.

*User-Agent*

These agents are programmed versions for users, through these agents they can communicate with controller agent to receive their required details regarding load demands and access data.

*Load Agent (LAG)*

Load agent predicts next day demand, and it is installed at each load center. LAG agent forecast the demand for the electricity from last five consecutive years' historical data. Load agent deals with SGC regarding power purchase and sends a message which includes a quantity of power and its price. The load can be critical and non-critical it will deal with it accordingly.

*Consumer Agent*

This agent makes sure to facilitate the buyer receives the required energy quantity as demanded. In case of disconnection, it will activate another link from his dedicated pool if the supplier is disabled. There is another reason that for change to another link sometimes is that the Co's currently using up increased from the provider's load. Each consumer, an agent, covers a priority that's specified once linked into the grid and might be customized by human interference at a later time is essential. The significance of this characteristic may be determined once the MG is managing low energy level for example if the buyer encompasses a low priority than it'll be allowed to consume a smaller quantity of energy rather than its traditional utilization. The distributional proportional of the energy to the CO's in this way is of priority. Such condition is for the time being till the MG is operating among traditional factors.

*Micro-Hydro Turbine Agent (MHTAG)*

The MHTAG Agent deals with SGC regarding power sale, it sends request message which includes the price and quantity of power for sale on availability.

*Diesel Generator Agent (DGAG)*

The DGAG Agent deals with SGC regarding power sale, it sends request message which includes the price and quantity of power for sale on availability.

*Substation Agent*

The substation agent can communicate with other grids, substations and even other entities outside the Microgrid. In different situations, it ensures that substation provides enough power to the grid and also have the authority/decision power to allow or stop any DG to generate power into the grid.

## 4.2. Agent Roles and Responsibilities

Every agent has autonomy to perform its task in his specific domain and Specific area, due to its goal-oriented behaviors. In this section, the proposed control architecture is defined on the bases of role, Skills, and functions. Functions are set of behaviors which are normally executed by agents. The collaborative diagram of the MAS illustrates the agent's interaction with each other and within the environment. Figure 5 provides a general consideration about agents that how these agents communicate with different Management level agents. It's also illustrating the requisite contents for the exchanges. The Multi-agent system is enrolling agents in different management levels through their consequent facilities in Directory Files associated. Therefore, when agents initiate to communicate with another agent, the agent requests the Facilitator agent to facilitate the requested service from the list of agents from Directory File. The sense behind the agent communication is shown in Figure 6.

The Message contents in essential part agent language in MAS design which can be defined through an appropriate ontology, it provides easy understanding among agents. In this paper smart grid ontology for real-time control proposed for smart grid which is shown in Figure 7.

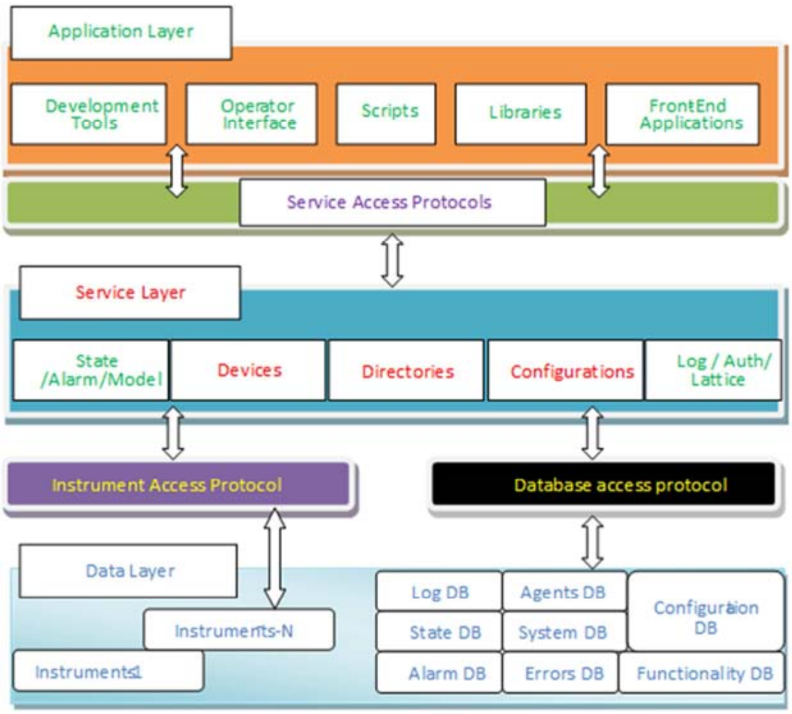


***Figure 5.*** *Multi agent's core network functions.*

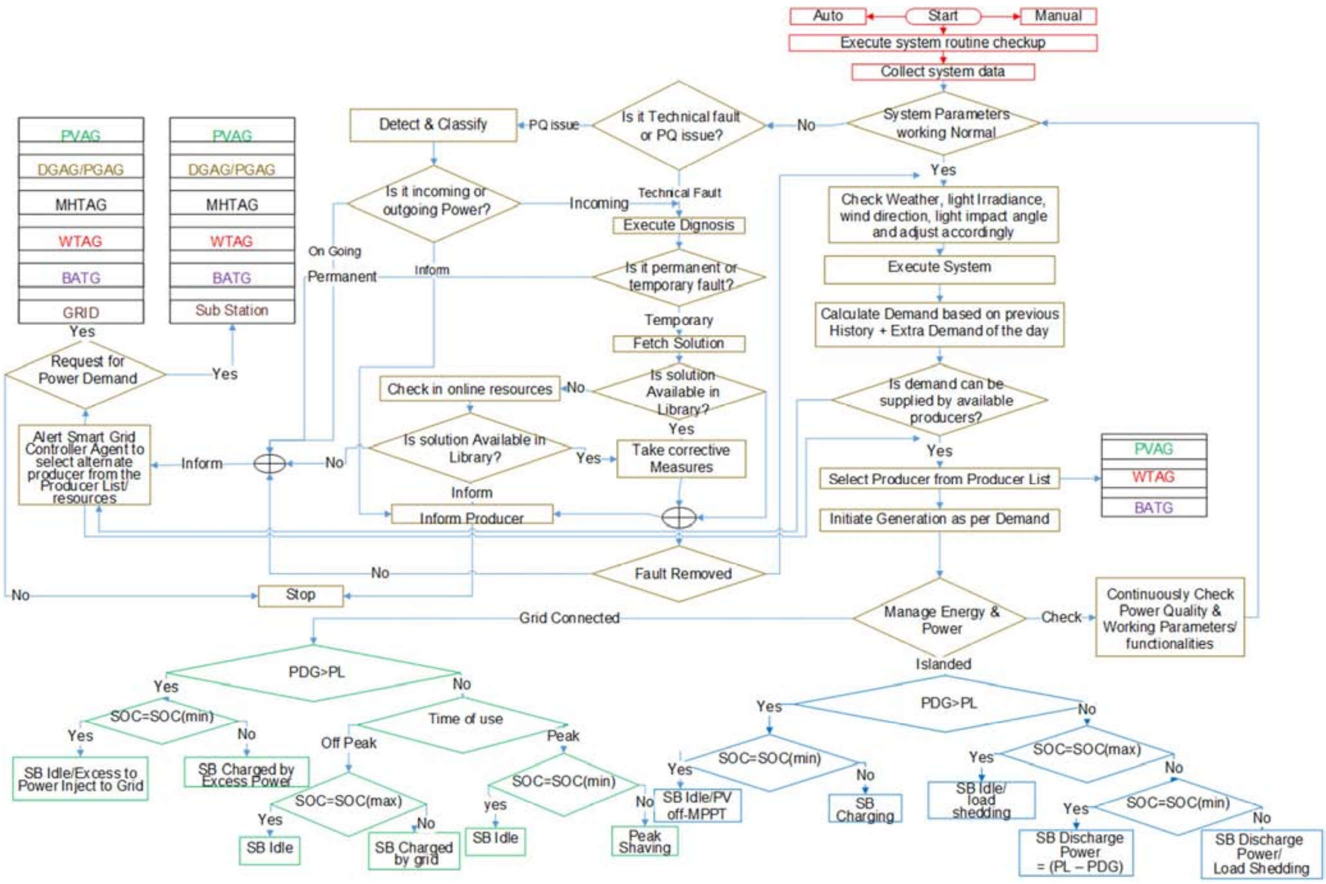


***Figure 6.*** *Flow System diagram.*

## 5. Real-Time Strategies

In the presented Hybrid system to Manage and Control, Detect and Reserve Power quality in real time scenario is complicated due to natural Phenomena of Sun irradiance and wind speed and direction of Movement which varies from time to time even so much that it even doesn't match the forecasted values that ultimately directly affect the load and micro sources production. This also affects short-term scheduling of market operations, i.e., scheduling of generating units after every specific time interval, Therefore to control short-term scheduling of market operations the desirable control is a real time for the process of Microgrid, which has to balance the consumption &Generation in real time by providing newly set spots to the power sources. The Proposed Model is a distributed real-time approach which provides advantages as Fast & Reliable, Secure, Smart, and Safe. In this type of approach, the task is divided according to roles and skills as given in Table 1. According to Proposed approach, the main responsibilities are given to the Lc's for loads and Mc's for Sources the Types of Powers are explained here.

i) Micro Grid: The Top level agents Control decide and ensure the exchange of Power as IMPORT or EXPORT form Main grid or Sub-Station to microgrid or vice versa.
ii) Non-Controllable Power: Wind turbines and PV panels are noncontrollable power sources in the Microgrid PV is operated with MPPT Concept and Wind Turbine is operated with CESS which can change its power product subject to our system requirements'.
iii) Fixed Power Source: The Battery is considered as a fixed power source in this proposed paper.
iv) Controllable Power Sources: The DG's which run with fuels attached to other Micro grids from where Microgrid can import power in grid-connected status depend on Top Level of agents control.

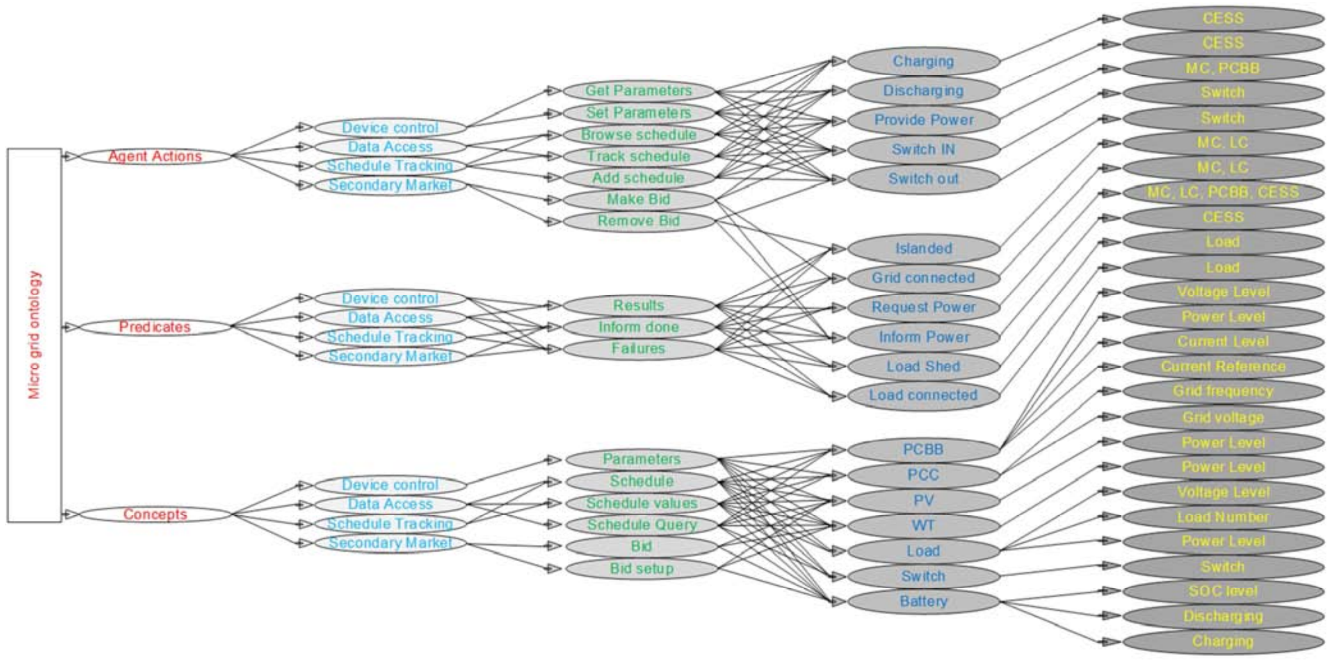


***Figure 7.*** *Hybrid Microgrid Ontology.*

## 5.1. To Reserve Power Quality While Grid Connected Micro-grid

The main role of the Micro-grid in the grid-connected mode is to accommodate the real or reactive power generated as per load demand by the micro sources with standard quality as desired. Secondly, the main grid frequency is maintained during the grid-connected mode. The MAS optimizes the sources of real power outputs. The foremost criteria for choosing power quality improvement and removing defects among micro sources are also minimized the operational expenditure of the sources and major defects.

## 5.2. To Reserve Power Quality While Islanded Micro-grid

The Microgrid is designed that during upstream outage condition it cut off itself from the main grid through a logical switch. At all points, the agents detect automatically any disturbance such as phase angles, frequency change or faults inside/outside at any connection points. If the error of a voltage is <3.5%, and the error of the phase angle is<10° while the error of a frequency is <0.1 Hz, then reconnection is acceptable. In the Islanded mode the support from the main grid is unable to provide, while frequency and voltage control in addition to real & reactive power balance are making available by grid itself. Due to the non controllable PV nature and wind power, micro-sources, for example CESS and DGs are accountable for making sure the balancing of local load demand and generation through absorbing & injecting the power, subject to the loads which are least important means non critical loads which will shaded if the existing generation is not enough to secure all the loads

# 6. Results and Discussion

The IEEE 1159-1995 PQ Standards [5] exhibit that all

Power quality disturbance has some distinctive characteristics, such as Typical Spectral Content, Magnitude, Polarity, duration/width and Amplitude as Shown in Table 2 that can be used for classification. The multi-agents are used to control the parameters of numerical models in [62] for power quality disturbance detection in Matlab simulation. The extracted power quality features from the detailed signal output are used to identify & differentiate between nature of waveform distortions and different types of Transients. As shown in Table 3 the multi-agents followed the decision rules for power qualities disturbances such as individual as well as combined with the presented control system. The power quality signals consist of flickers, harmonics, notching, impulsive & oscillatory transients, Sag, swell, interruption, and DC-offset are produce using the micro-grid model and synthetic according to the power quality standards recommended by IEEE [5]. These power quality disturbances obtained closely depict real-time disturbances because they have been simulated over the defined parameter ranges for the Multi-agent system because the real-time disturbances availability is very limited therefore these Synthetic data of Power Quality disturbances are analyzed for the ability of the control system.

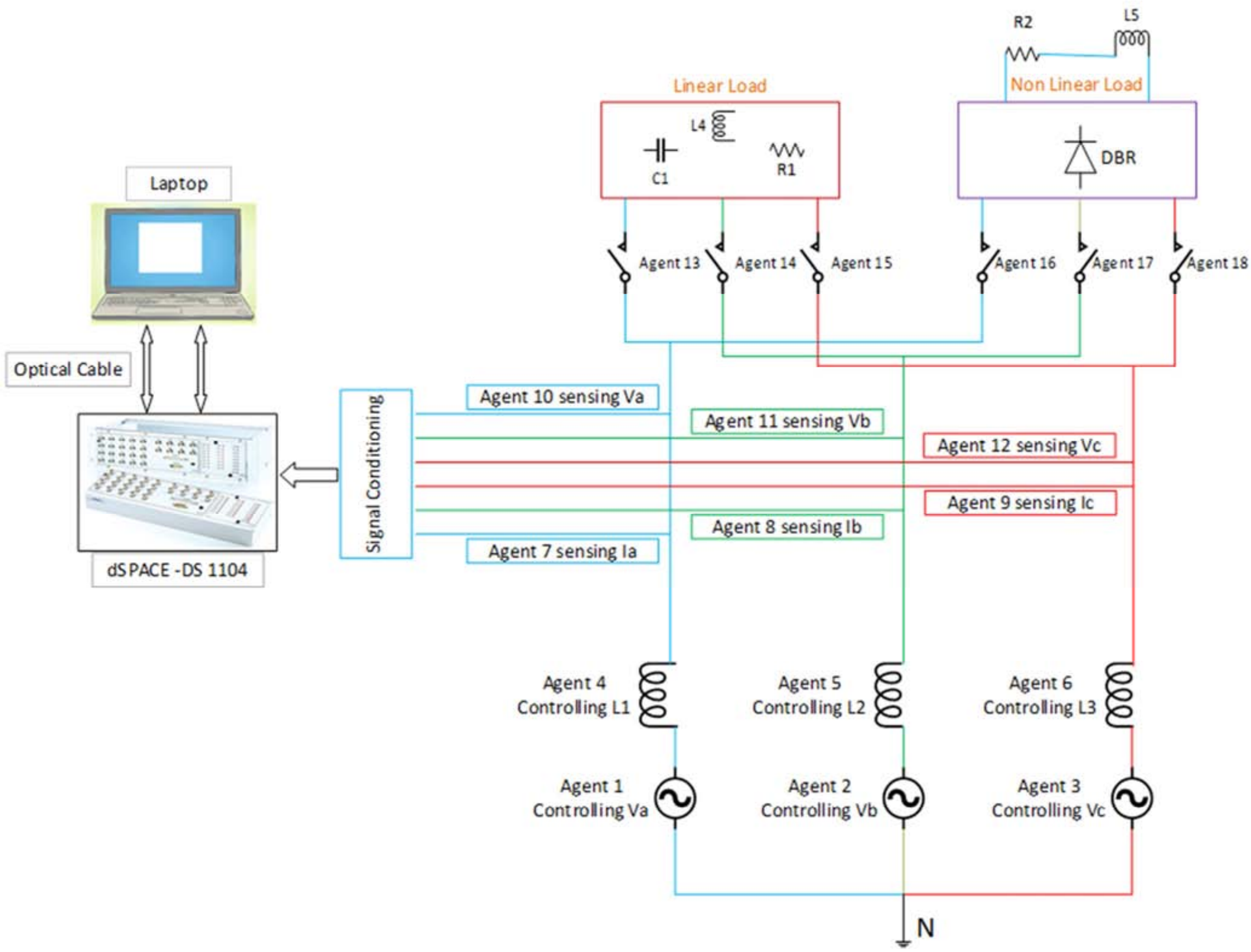


***Figure 8.*** *Laboratory hardware Prototype to generate real-time PQ disturbance.*

***Table 3.*** *IEEE Power Quality standards 1159-2009 [5] defined for distinctive specification of disturbances.*

| Types of PQ Disturbance | Typical Duration | Typical Amplitude | Typical Spectral Content |
|---|---|---|---|
| Transients | Ns-ms | 0.8 Pu | 5kHz-5 MHz |
| Sag | >0.5 Cycle | 0.1 - 0.9 pu | ~ |
| Swell | >0.5 Cycle | 1.1 - 1.8 pu | ~ |
| Interruption | >0.5 Cycle | < 0.1 pu | ~ |
| Flicker | >0.5 Cycle | 0.9 - 1.1 pu | < 25 kHz |
| Notching | Steady state | ~ | ~ |
| Harmonics | Steady state | 0 - 0.2 pu | 0 - 6 kHz |
| Interharmonics | Steady state | 0 - 0.2 pu | 0 - 6 kHz |
| Noise | Steady state | 0 - 0.01 pu | Broadband |

***Table 4.*** *Numerical Modeling of Simulation Disturbances.*

| Label-ID | PQ Disturbance | Model | Parameters Controlled by Multi Agents |
|---|---|---|---|
| ID-1 | Pure Sine | $S(t) = A_{sin(\omega t)}$ | A=1(pu),$\omega = 2\pi 50 rad/sec$ |
| ID-2 | Flicker | $S(t) = (1 - \gamma_f sin(\alpha\omega t))_{sin(\omega t)}$ | 0.1$\leq \gamma_f \leq 0.2,5, \leq \alpha \leq 20Hz$ |
| ID-3 | Notch | $S(t) = Sin_{\omega t} + sign(sin(\omega t)) \times [\sum_{n=0}^{9} N \times \{V(t-(t(t_1+0.02n)) - V(t_2+0.02n))\}])$ | 0.1$\leq K \leq 0.4,0, \leq t_2, t_1 \leq 0.5T, 0.01T \leq \tau \leq 0.05T$ |
| ID-4 | Oscillatory Transient | $S(t)$ =($Sin_{\omega t}$+$\gamma_e^{\frac{t-t_1}{t}} Sin_{\omega m}(t-t_1)\{$V($t_2$- V($t_1$)} | 0.1 $\leq \gamma \leq 0.8, 0.5T, \leq t_2 - t_1 \leq 3T, 8ms \leq \tau \leq 40ms, 300 \leq f_n \leq 900Hz$ |
| ID-5 | Sag | $S(t)$ =(1-$\gamma(V(t-t_1)$- $s(t-t_1)$)) $A_{sin(\omega t)}$ | 0.1$\leq \gamma \leq 0.9, \leq t_2 - t_1 \leq 9T,$ |
| ID-6 | | $S(t)$ =(1-$\gamma(V(t-t_1)$- $s(t-t_1)$)) $A_{sin(\omega t)}$ | 0.1$\leq \gamma \leq 0.8, \leq t_2 - t_1 \leq 9T$ |
| ID-7 | Swell | $S(t)$ =(1-$\gamma(V(t-t_1)$- $s(t-t_1)$)) $A_{sin(\omega t)}$ | 0.9$\leq \gamma \leq 0.1, \leq t_2 - t_1 \leq 9T$ |
| ID-8 | Spike | $S(t) = sin(\omega t) + sign(sin(\omega t)) \times [\sum_{n=0}^{9} N \times \{V(t-(t(t_1+0.02n)) - V(t_2+0.02n))\}])$ | 0.1 $\leq K \leq 0.4, 0 \leq t_2, t_1 \leq 0.5T, 0.01T \leq t_2 - t_1 \leq 0.05T$ |
| ID-9 | Harmonics | $V(t) = \gamma_1 sin(\omega t) + \gamma_3 sin(3\omega t) + \gamma_5 sin(5\omega t) + \gamma_7 sin(7\omega t)$ | 0.05$\leq \gamma_3, \gamma_5, \gamma_7 < 0.15 \sum \gamma_f{}^2 = 1$ |

In this proposed control system method, the combination of SSD based method and Symmetrical Components Method is used to detect and classify as a general with a sampling rate 20 kHz and quantized with a resolution of 12 bits. The outcome in Figure 9 & 10 show the benefits of SSD and Symmetrical Components methods for both individual and combined power quality activities detection and classification in noisy and noiseless circumstances. Multi-agent system on the basis of SSD method was accurately classifying all 32 PQ disturbances (11 Individual & 21 Combined) through varying SNRs in dB from 30 - 45 as shown in Table 5 more efficiently and to verify the results the same proposed control system is applied to wavelet network, fuzzy & ST, Dynamic & ST, ADALINE \& FFNN as shown in Table 6 shows the same good results. The fundamental frequency is varying in-between 48Hz to 52Hz; The regularization parameter λ is set to 0.1 to detect disturbance within the lowest magnitude range described in [5] while considering the noise reduction and computational time.

***Table 5.*** *Decision-based rules for Multi-agents to Classify.*

| Labal | Disturbances | Decision Rules for classification |
|---|---|---|
| ID-1 | Normal | (KA1<0.01) && (0.9<CJ1<1.1) && (CJ2<0.01) |
| ID-2 | Flicker | (KA1<0.01) && (0.9<CJ1<1.1) && (CJ2<0.01) && (1<CJ6<25) |
| ID-3 | Impulsive | (KA1<0.01) && (0.9<CJ1<1.1) && (CJ2<0.01) && (KA3=+1) && (KA2< 5ms) && KA4>1 |
| ID-4 | Multiple Notch | (KA1<0.01) && (0.9<CJ1<1.1) && (CJ2<0.01) && (KA3=-1) && (KA2< 5ms) && (KA4>2) |
| ID-5 | Single Notch | (KA1<0.01) && (0.9<CJ1<1.1) && (CJ2<0.01) && (KA3=-1) && (KA2< 5ms) && (KA4>1) |
| ID-6 | Oscillatory (Osc) | (KA1<0.01) && (0.9<CJ1<1.1) && (CJ2<0.01) && (KA3=-1) && (KA2< 5ms) && (KA4<2) |
| ID-7 | Sag | (KA1>0.01) && (KA4 <2) && (KA5=-1) && (KA2< 5ms) && (CJ1<1.0) && (CJ5>20ms) && (CJ2>0.1) && (0.1<CJ3<0.9) && (CJ4<0.01) |
| ID-8 | Swell | (KA1>0.01) && (KA4 <2) && (KA5=-1) && (KA2< 5ms) && (CJ1<1.0) && (CJ5>20ms) && (CJ2>0.1) && (1.1<CJ3<1.8) && (CJ4<0.01) |
| ID-9 | interruption | (KA1>0.01) && (KA4 <2) && (KA5=-1) && (KA2< 5ms) && (CJ1<1.0) && (CJ5>20ms) && (CJ2>0.1) &&(CJ3<0.1) && (CJ4<0.01) |
| ID-10 | DC-offset | (KA1>0.01) && (KA4 <2) && (KA5=1) && (KA2< 5ms) && (0.9<CJ1<1.1) && (CJ5>20ms) && (CJ2>0.1) && (48<CJ6<52) |
| ID-11 | Harmonics | KA2=B (dur) && (KA4=1) && (KA>20) |
| ID-12 | Sag+ Osc | (ID-7=True) && (KA3=0) && (5ms<KA<50ms) && KA4<2) |
| ID-13 | Swell + Osc | (ID-8=True) && (KA3=0) && (5ms<KA<50ms) && KA4<2) |
| ID-14 | Flicker+ Osc | (ID-2=True) && (KA3=0) && (5ms<KA<50ms) && KA4<2) |
| ID-15 | Dc-offset+ Osc | (ID-10=True) && (KA3=0) && (5ms<KA<50ms) && KA4<2) |
| ID-16 | interruption+ Osc | (ID-9=True) && (KA3=0) && (5ms<KA<50ms) && KA4<2) |
| ID-17 | spike + Osc | (ID-3=True) && (KA3=0) && (5ms<KA<50ms) && KA4<2) |
| ID-18 | Sag+ Notching | (ID-7=True) && (KA3=-1) && (KA2<50ms) && (KA4>1) |
| ID-19 | Swell+ Notching | (ID-8=True) && (KA3=-1) && (KA2<50ms) && (KA4>1) |
| ID-20 | Flicker+ Notching | (ID-2=True) && (KA3=-1) && (KA2<50ms) && (KA4>1) |
| ID-21 | DC-offset+ Notching | (ID-10=True) && (KA3=-1) && (KA2<50ms) && (KA4>1) |
| ID-22 | Interruption+ Notching | (ID-9=True) && (KA3=-1) && (KA2<50ms) && (KA4>1) |
| ID-23 | Sag+ Spike | (ID-7=True) && (KA3=+1) && (KA2<50ms) && (KA4>1) |
| ID-24 | Swell+ + Spike | (ID-8=True) && (KA3=+1) && (KA2<50ms) && (KA4>1) |
| ID-25 | Flicker+ Spike | (ID-2=True) && (KA3=+1) && (KA2<50ms) && (KA4>1) |
| ID-26 | DC-offset+ Spike | (ID-10=True) && (KA3=+1) && (KA2<50ms) && (KA4>1) |
| ID-27 | interruption+ Spike | (ID-9=True) && (KA3=+1) && (KA2<50ms) && (KA4>1) |
| ID-28 | Sag+Flicker | (KA1>0.01) && (KA4<2) && (KA4<2) && (KA2<5ms) &&(CJ1<1.0) && (0.01 <CJ4<0.05) &&(0.1<CJ3<0.9) |
| ID-29 | Swell +Flicker | (KA1>0.01) && (KA4<2) && (KA4<2) && (KA2<5ms) &&(CJ1<1.0) && (0.01 <CJ4<0.05) &&(1.1<CJ3<1.8) |

| Labal | Disturbances | Decision Rules for classification |
|---|---|---|
| ID-30 | Harmonics+Flicker | (ID-11=True) && (ID-2=True) |
| ID-31 | Harmonics+Sag | (ID-11=True) && (0.1<CJ3<0.9) && (CJ4>0.05) |
| ID-32 | Harmonics+ Swell | (ID-11=True) && (1.1<CJ3<1.8) && (CJ4>0.05) |

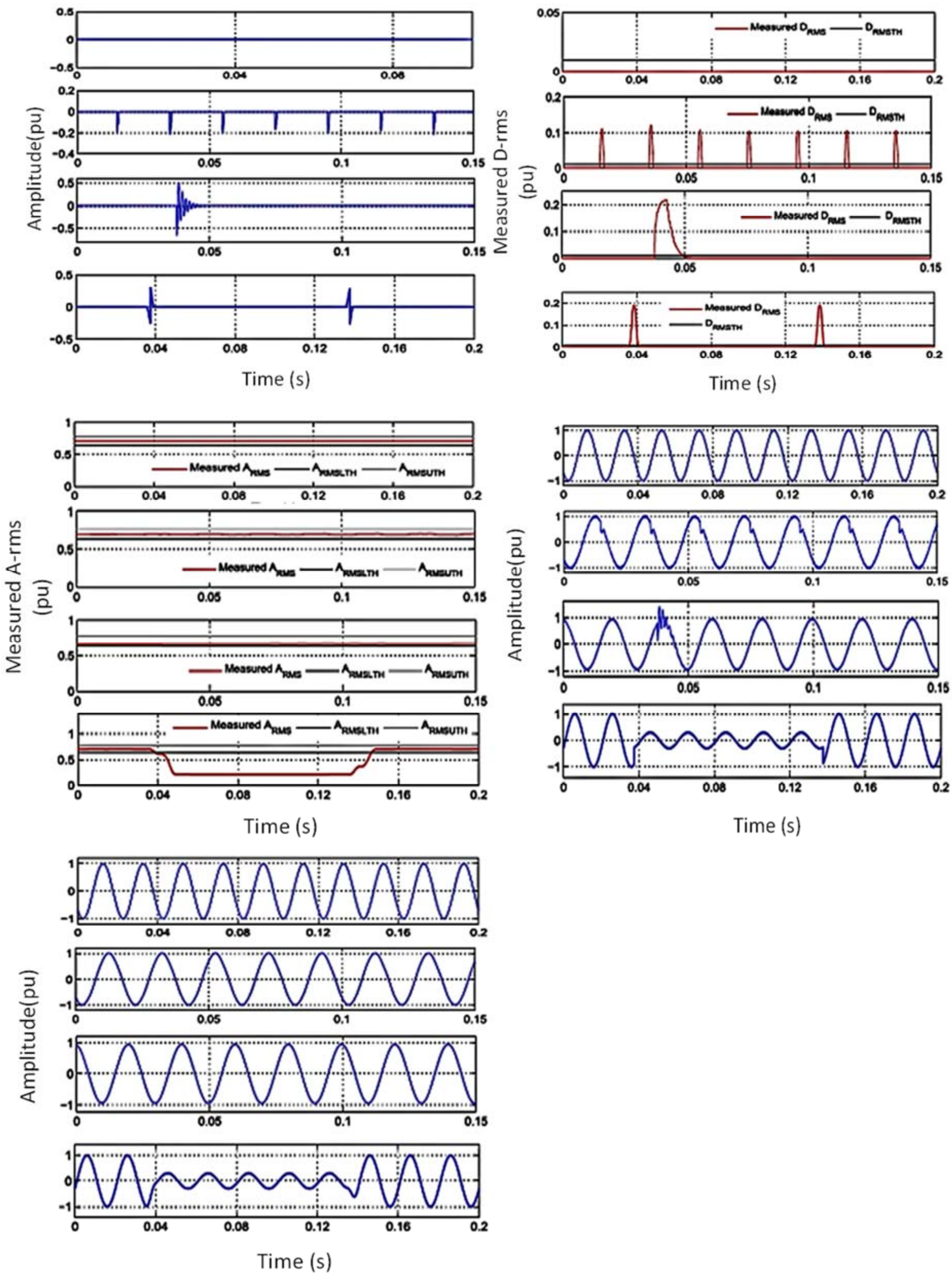


***Figure 9.*** *Fundamental, Normal, oscillatory transients, voltage sag, and notch sag. Signals with Extracted feature along with signal feature measured rms envelope, with extracted approximation and approximation signal measured rms envelope.*

***Table 6.*** *Power Quality disturbances classification Results of Different SNRs.*

| Labal | Disturbances | Detection and Correct Classification Accuracy (%) with Different SNRs | | | | | |
|---|---|---|---|---|---|---|---|
| | | Detection | Clean | 30dB | 35dB | 40dB | 45dB |
| ID-1 | Normal | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-2 | Flicker | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-3 | Impulsive | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-4 | Multiple Notch | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-5 | Single Notch | 100 | 100 | 99.33 | 99.33 | 100 | 100 |
| ID-6 | Oscillatory (Osc) | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-7 | Sag | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-8 | Swell | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-9 | interruption | 100 | 100 | 99 | 100 | 100 | 100 |
| ID-10 | DC-offset | 99 | 99.33 | 99 | 99.33 | 99.33 | 99.33 |
| ID-11 | Harmonics | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-12 | Sag+ Osc | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-13 | Swell + Osc | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-14 | Flicker+ Osc | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-15 | Dc-offset+ Osc | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-16 | interruption+ Osc | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-17 | spike + Osc | 97 | 96.33 | 96 | 96.33 | 96.33 | 96.33 |
| ID-18 | Sag+ Notching | 96 | 96.67 | 99.33 | 96.67 | 96.67 | 96.67 |
| ID-19 | Swell+ Notching | 96.47 | 95.33 | 95 | 95.33 | 95.33 | 95.33 |
| ID-20 | Flicker+ Notching | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-21 | DC-offset+ Notching | 95 | 94.67 | 93.33 | 93.67 | 96.67 | 96.67 |
| ID-22 | Interruption+ Notching | 96.4 | 96.33 | 96 | 96.33 | 96.33 | 96.33 |
| ID-23 | Sag+ Spike | 97 | 96.67 | 95.67 | 95.67 | 96.67 | 96.67 |
| ID-24 | Swell+ + Spike | 98 | 97 | 96.33 | 96.67 | 97 | 97 |
| ID-25 | Flicker+ Spike | 100 | 100 | 100 | 100 | 100 | 100 |
| ID-26 | DC-offset+ Spike | 97 | 96 | 95.67 | 96 | 96 | 96 |
| ID-27 | interruption+ Spike | 99 | 98.67 | 98.33 | 98.67 | 98.67 | 98.67 |
| ID-28 | Sag+Flicker | 98 | 97.67 | 97 | 97.33 | 97.67 | 97.67 |
| ID-29 | Swell +Flicker | 98.6 | 98.67 | 98 | 98.33 | 98.67 | 98.67 |
| ID-30 | Harmonics+Flicker | 94 | 93.67 | 92 | 92.67 | 93.33 | 93.67 |
| ID-31 | Harmonics+Sag | 91 | 89.67 | 88.33 | 88.67 | 89 | 89 |
| ID-32 | Harmonics+ Swell | 92 | 91.33 | 89 | 89 | 91.33 | 91.33 |

***Table 7.*** *Percentage of Correct Classification Result in terms of Performance Comparison.*

| PQ Disturbance | Wavelet Network | | Fuzzy & ST | | Dynamic & ST | |
|---|---|---|---|---|---|---|
| | Original Classification | Classification with proposed Multi agent system | Original Classification | Classification with proposed Multi agent system | Original Classification | Classification with proposed Multi agent system |
| Normal | ~ | ~ | ~ | ~ | 100 | 100 |
| Transient | 98.67 | 99 | 94 | 98 | 99 | 99.67 |
| Impulsive/Spike | ~ | ~ | 100 | 100 | 97 | 99.67 |
| Notch | 97.33 | 99 | 96 | 99 | 98 | 99.67 |
| Flicker | 98.67 | 99 | ~ | ~ | 96 | 98 |
| Interruption | 98 | 99.33 | 96.66 | 98.67 | 96 | 99.33 |
| DC-offset | 97.33 | 98.67 | ~ | ~ | ~ | ~ |
| Sag | 98.67 | 99.33 | 97.33 | 98.67 | 99 | 99.67 |
| Swell | 99.33 | 99.67 | 98.66 | 99.67 | 98 | 99.33 |
| Harmonics | 99.33 | 99.67 | 100 | 100 | 99 | 99.67 |
| Sag+Transient | 98.18 | 98.66 | 99.33 | 99.67 | ~ | ~ |
| Swell+Transient | 98.18 | 99.33 | 100 | 100 | ~ | ~ |
| Spike+Transient | ~ | ~ | 100 | 100 | ~ | ~ |
| Sag +Flicker | 96.36 | 96.67 | ~ | ~ | ~ | ~ |
| Swell+Flicker | 96.36 | 98.33 | ~ | ~ | ~ | ~ |
| Flickers+ Harmonics | 98.18 | 99.67 | 100 | 100 | ~ | ~ |

| PQ Disturbance | Wavelet Network | | Fuzzy & ST | | Dynamic & ST | |
|---|---|---|---|---|---|---|
| | Original Classification | Classification with proposed Multi agent system | Original Classification | Classification with proposed Multi agent system | Original Classification | Classification with proposed Multi agent system |
| Sag+Harmonics | 98.18 | 99.67 | ~ | ~ | 97 | 98.67 |
| Swell+ Harmonics | 98.18 | 99.67 | 96 | 99 | 98 | 99.33 |

***Table 8.*** *Continued.*

| PQ Disturbance | ADALINE & FFNN | | SSD & HDT | |
|---|---|---|---|---|
| | Original Classification | Classification with proposed Multi agent system | Original Classification | Classification with proposed Multi agent system |
| Normal | 100 | 100 | 100 | 100 |
| Transient | 98 | 99.67 | 100 | 100 |
| Impulsive/Spike | 97 | 99.67 | 100 | 100 |
| Notch | 97 | 100 | 100 | 100 |
| Flicker | 94 | 98 | 100 | 100 |
| Interruption | 100 | 100 | 98 | 100 |
| DC-offset | ~ | ~ | 98.67 | 99.33 |
| Sag | 100 | 100 | 100 | 100 |
| Swell | 100 | 100 | 100 | 100 |
| Harmonics | 98 | 99 | 100 | 100 |
| Sag+Transient | ~ | ~ | 100 | 100 |
| Swell+Transient | ~ | ~ | 100 | 100 |
| Spike+Transient | ~ | ~ | 100 | 100 |
| Sag +Flicker | ~ | ~ | 97.33 | 97.33 |
| Swell+Flicker | ~ | ~ | 98 | 98 |
| Flickers+ Harmonics | ~ | 94 | 96.67 | 90 |
| Sag+Harmonics | ~ | 98 | 99.33 | 83.33 |
| Swell+ Harmonics | ~ | 97 | 98 | 82.67 |

In the Table 4 some decision rules for detection & classification are defined with specific terminologies such as KA1: Maximum rms (Kmax), KA2: Duration (KT), KA3: Peak polarity (DSIGN), KA4: Number of isolated events (KNE), KA5: Time of events incidence (KTOC), KA6: Autocorrelation of detail signal (KACF), CJ1: The complete rms envelope xarmsmean value, CJ2: The complete rms envelopestandard deviation, CJ3: The rms envelopemean value xarms during the detected event portion, CJ4: The envelop Xarms rms Standard deviation value throughout the spot occasion segment, CJ5: is resolute as a time detection event duration value where higher enormity threshold is exceeded constantly by rms envelop xarmsARMSUTH of 1.1 pu and lower enormity threshold ARMSLTH of 0.9 pu, CJ6 by means of index of min value of autocorrelation frequency value is measured with sampling rate of the rms envelope xarms of the signal. The CJ6 value for flickers is below 25 Hz whereas CJ6 value dc-offset events are between 48 and 52. The implementation of proposed control system LV- 55P (current sensor), LV-25P (hall effect voltage sensor) and DSP-dspace 1104 (digital signal processor) are utilized as an agent's for the current and voltage sensing. As in a practical laboratory prototype distribution system, linear and nonlinear loads are used. To generate harmonics and notches a single phase rectifier is used, while switching at the PCC (point of common coupling) the high rated linear load, the Voltage swell and sag have been recorded by multi-agents. The acquisition and generation of real-time PQ disturbances in the prototype are shown in Figure 9. In the laboratory, the power quality signals are captured and detected as shown in Figure 10 (a - d). The presented control technique is used in unusual different for cases of voltage interruption, voltage swell, voltage sag, voltage notches which are the PQ disturbances

Multi-agents are identifying the PQ disturbances from the database which are feed as per parameters of different numerical models. It follows decision rules as shown in Table 3 to declare the category of Power Quality It has many advantages such as it decreases the average laps-time burden as shown in Table 7.

***Table 9.*** *Comparison of Computational Burden with/without Multi agent system.*

| Method | Computation Burden | Average Lapse Time (10 Cycle) | Average Lapse Time with Multi agents (10 cycle) |
|---|---|---|---|
| Symmetric Components | Multiplication and addition in PLL and symmetric component | 0.031 s | 0.021 s |
| Wavelets | L*N2 where L is the number of decomposition levels | 0.045 s | 0.033 s |
| Hilbert Huang Transform | Depends upon the stopping criterion and number of empirical mode decompositions | 0.563 s | 0.396 s |
| S-Transform | N*(N+N*logN) where N is the data points | 0.921 s | 0.410 s |

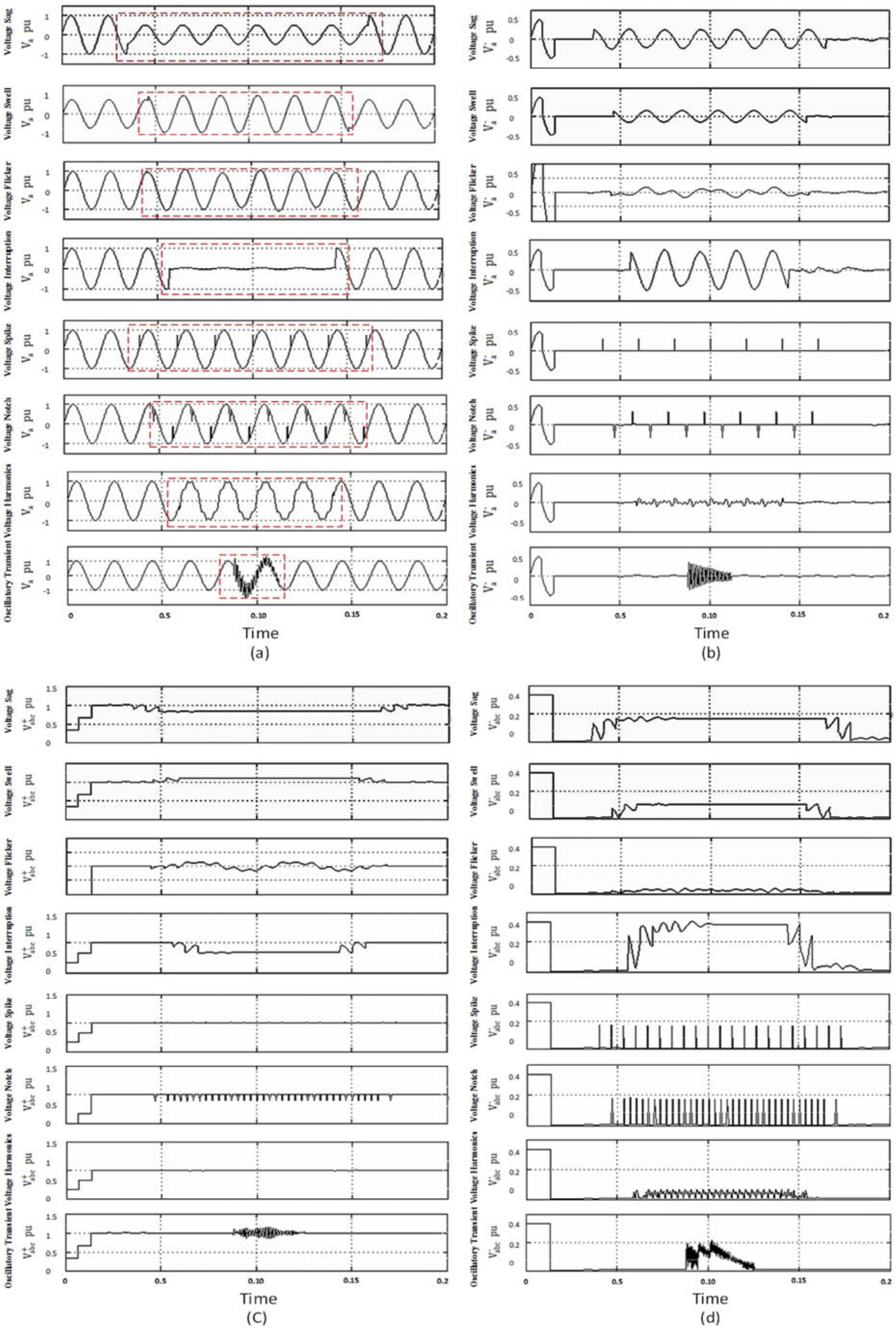


***Figure 10.*** *(a) Different Power Quality disturbances. (b) Phase disturbances. (c) Positive Instantaneous Peak Contour. (d) Negative Instantaneous Peak Contour.*

## 7. Conclusion

This paper introduced the multi-agent system theory into the classification of PQD's it would appear that this is the first time agents are used for this task, self-supervision in multi-agents and hierarchal features extraction in system coordination and communication cannot only effectively avoids the defects of previous methods, but also address the problems of how to select and optimal features set for detection, classification based on the signal variance acting as an auxiliary method distinguishes all the types of PDQ's from different results and its validation. It is concluded that the proposed system can work in large scale with all interfaces especially the recognition of PDQ's types, faults, system failure and it also detects the noises and sudden defects. These learning agents can be easily implemented in different environments with real-time parameters in the real field.

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