

# Multi-Agent System Based Active Power Management in Micro-Grid

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**Abstract**—Microgrid (MG) comprises of distributed generations (DGs), energy storage system and different types of loads in grid-connected or in standalone mode. Most of the distributed generations are intermittent in nature and the converters are interfaced. Also, the output power from these DGs may inject harmonic distortion, which will deteriorate the power quality. The existing controller for inverter requires optimization algorithm for every step and has complex tuning process. So as to guarantee the steadiness of the MG, the DG sources may interact with neighboring DGs via Multi-Agent System (MAS). The upper level multi-agent instigates distributed communication via consensus amid neighboring agents are for MG power management to yield a reference signal for the lower level controller. The multi-agent system in lower level employs proposed Adaptive Robust Set point Tracking, Disturbance Rejection (ARSPTDR) controller with Optimal Selective Harmonic Elimination-Pulse Width Modulation (OSHE-PWM), thereby coordinated by power management strategy. This ARSPTDR controller provides stable performance and maintains the grid stability and OSHE-PWM reduces the harmonic distortion. The proposed controller deals through the snag of existing controller. Simulation studies in MATLAB/SIMULINK environment demonstrate the efficacy of the proposed control method.

**Index Terms**—Harmonic Distortion, Optimal Selective Harmonic Elimination-Pulse Width Modulation, Multi-Agent System, consensus algorithm, power quality improvement.

## I. INTRODUCTION

Energy demand of the nations has been escalating day by day due to developing technological needs and expanding populace of countries. Besides optimal consumption along with generation of electricity, the desire of public in modern societies requires the amalgamation of astute Power Management Systems (PMSs) [1]. The growth of Renewable Energy

Resources (RESs) such as Photovoltaic (PV), wind turbine, etc. have been extensively utilized to yield clean electrical power and rough guide for the perception of Microgrid (MG) [2]. MG is a low-voltage distribution network having a small-scale bunch of various controllable and uncontrollable resources/loads at end user. These resources include on-site generators (both renewable and non-renewable dispatchable generators), Energy Storage Systems (ESS), and fixed and controllable loads [3]. Similar to the wholesale power grid, MG also generates, dispenses, and regulates the electricity flow to consumers [4].

Distributed power generation from clean and viable energy sources close to end users is reshaping the structure of the current electrical systems [5]. Distributed generations (DGs) and local energy storage systems can be systematized into a self-sufficient MG to diminish the power intermittency of renewable DGs and enrich power quality, efficiency, and reliability for the utility and consumers mutually [6]. DGs are often associated to the MG over power electronic interface, which is aimed at regulating the power injection. MG either operates in islanded/standalone mode or grid-connected mode [7]. Under typical situations, MG takes part in utility grid-connected power system operations, contributing surplus power, providing auxiliary services, or acquiring electricity from the wholesale power system. Under crisis circumstances, MG can isolate, or island, from the utility power system and operate autonomously, inside the point of confinement [8]. Each MG is a self-sustainable energy unit with its own management and control capabilities, which is capable to continue its functioning and serving consumers though when it is islanded from the main grid [9]. The interconnection of distributed generators to the main grid via power electronic converters features better

effectiveness, greater reliability, and more control flexibilities [10]. Power electronic converters such as AC-AC converter, AC-DC converter (rectifier), DC-DC converter and DC-AC converters (inverter) are utilized for power conversion [11]. Since the resources and loads in a MG may be highly disseminated in space, an extensive power management strategy is necessary for regulating the numerous terminals coordinately. The functions of such management include regulating power flow, guaranteeing stability, upgrading power quality, seeking economic benefits, etc. [12].

Currently, the power system engineers concentrate on the potential significance of Multi-Agent System (MAS) technology to the power industry applications. In MAS, it may be physical environment (e.g., the power system), or it may be the computing environment (e.g., data sources, computing resources, and other agents). An agent may regulate the environment by enchanting some activity: either physically (for example, shutting a typically-open point to reconfigure a network), or something else (for example, stowing analytic data in a database to access) [13]. MAS is standout amongst the most exciting and the fastest developing areas in agent oriented technology, which deals with modeling of autonomous decision making entities. MAS modeling of a MG is extraordinary compared to other decision to make much insightful power framework, where each necessary part is denoted by an intelligent autonomous agent. It provides a platform to utilize combination of artificial intelligence and precise tools to decide agents' optimal activities [14].

A handful of researches are available in the literature. Fadoul *et al.* [15] have utilized MAS for a distinctive Cyber-Physical MG System (CPMS). Based on the obtained global information via MAS, automatic generation control and automatic voltage control were used for droop control that dealt with the snag of customary droop control. K Nunna and S Doolla [16] have introduced a two-level architecture for distributed resource management for various MGs by means of MAS. The buyers and sellers energy market were matched by means of naive auction algorithm. Two case studies were presented with two and four interconnected MGs participating in a market. Tianqiao Zhao and Zhengtao Ding [17] have presented two-level optimization system for the distributed optimal resource management in view of a multi-agent

system framework. This technique just requires the data among neighboring members without central control coordination, and in chorus achieves resource optimization in a finite-time limited time while keeping up the supply-demand balance.

Foo *et al.* [18] have represented a respective agent at every DG and all price-sensitive load to perform different tasks, such as planning, coordination and market clearing subject to system, DG and load constraints. Chun-Xia Dou and Bin Liu [19] have studied the keen control issue for a self-sufficient MG with a specific end goal to keep up the safe voltages and amplify financial and environmental benefits. Extensive power management strategies for MG are required for achieving the various objectives: 1) proficiently share power from the DG units for the load requirements; 2) when the system changes its operating mode, it will rapidly react to transients and maintain stability; 3) with a view to balance the power and reinstate voltage deviations, it determines the final set-points for the power generation in DG units. Therefore, the control strategy is required in the converter for power management amid different DG in a MG.

In this paper, an inclusive control strategy for power management in MG is done via multi-agent system. For controlling and providing stable operation, Adaptive Robust Set Point Tracking Disturbance Rejection (ARSPTDR) controller with Optimal Selective Harmonic Elimination – Pulse Width Modulation (OSHE-PWM) is instigated in inverter via multi-agent system in order to generate stable AC power to the microgrid. ARSPTDR controller is employed to control the voltage/frequency of the inverter to activate the system in either grid-connected mode or in islanded mode. The input current is generated from various DGs and storage devices, to generate power to the load and also for the main grid. The effectiveness of proposed approach is demonstrated on the test cases.

## II. MULTI-AGENT SYSTEM ARCHITECTURE OF AN MG

A grid-connected MG is considered and the structure of MG is illustrated in Figure 1, composed of DGs, energy storage devices and loads. In this section, the communication network topology for MG, the agents and cost function of every agent in MG are defined.

A. Multi-Agent System Framework

The MG comprises of main grid, DG units, Battery Energy Storage (BES) and non-controllable load demands in MAS framework. A Point of Common Coupling (PCC) of the main grid is utilized to quantify the power delivered/introverted and to select the operation mode of the MG. Every partaker in the MAS framework is consigned to an intellectual agent that can interrelate with its neighboring agents. A bi-level control model for power management, in particular, the upper-level control and lower-level control, is conveyed to every single agent as described in Figure 1 for coordinating the operation of these units. The upper-level control is a communication network for each agent to exchange data that is produced by an optimal technique and sets the set-points for each agent. Both the control mode and the physical agent are located at the lower-level control. Following the adaptive set-point tracking, disturbance rejection control mode is exploited to regulate the power output of the agent to the set-point signal produced by the upper-level, and the settings of different control modes can be decided by its operation condition locally. Then, the physical agent is the electrical equipment to convey the power produced/consumed.

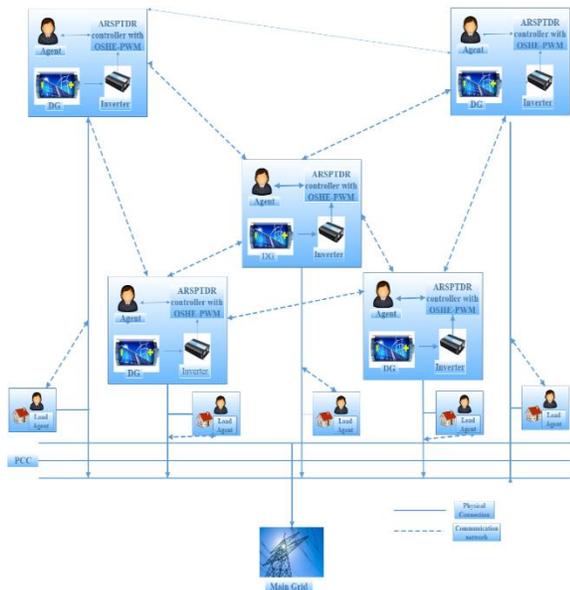


Figure 1: Multi-Agent Framework for Power Management

B. Agent Description in MAS framework  
1) Storage Agent:

Incorporating storage agents to a microgrid may require additional costs. Hence, when the MG is associated to main grid, the cost function for generating the electricity is low. At that time, the storage agent is ideally to charge the storage unit, when the MG operates in the islanded mode, and the storage agent discharges when the electricity rate is high. The charging ability of the storage battery is

$$BP_{in} = \min\left(\frac{P_{max} - S(1 - \ell\varepsilon)}{\Delta T}, BP_{max}\right) \tag{1}$$

$$BP_{out} = \min\left(\frac{S(1 - \ell\varepsilon) - P_{min}}{\Delta T}, BP_{max}\right) \tag{2}$$

where  $BP_{in}$  and  $BP_{out}$  is the storage system ability to charge and discharge of power;  $\Delta T$  is the duration of the commitment interval;  $BP_{max}$  is the maximum capacity of the storage system kW;  $S$  is the status of the system at the time interval;  $\ell$  is the elapsed time in months; and  $\varepsilon$  is the self-draining factor of the system.

C. Grid-connected MG Agent

When MG operated in grid-connected mode, the main grid agent monitors the power generated from the MG and main grid. Accordingly, the MG updates the electricity price based on the main grid. The cost function for grid connected mode is

$$C_g = C_e \cdot P_{mg} \tag{3}$$

where  $C_g$  is the cost for the loads during grid connected mode;  $C_e$  is the current electricity price; and  $P_{mg}$  is the power generated by the MG and the main grid.

D. Islanded MG Agent

The islanded MG ensures the supply-demand balance in a cost-effective way. In islanded MG, the power management is to regulate the energy produced by the DG units to match the demand plus losses. The generation of electricity cost at the islanded mode is high to benefit the utility provider, who provides electricity to consumers using MG. The cost function of the energy storage agent during islanded microgrid is

$$C_i = x + y(BP_{out} + 3P_{max}(1 - SOC)) + z3P_{max}(1 - SOC)^2 \tag{4}$$

$$\text{where } P_{min} \leq BP_{out} \leq P_{max}$$

where  $x$ ,  $y$  and  $z$  are the quadratic coefficients;  $P_{min}$  and  $P_{max}$  are the minimum and maximum charging rate of battery;  $SOC$  is the current state of charge.

Subjected to constraints

$$\sum_{i=1}^{DG} P_i = P_L \tag{5}$$

$$P_i^{min} \leq P_i \leq P_i^{max} \tag{6}$$

where  $P_i^{min}$  and  $P_i^{max}$  is the minimum and maximum power generated by the DG.  $P_i$  is the power generated by the  $i^{th}$  DG and  $P_L$  is the power demanded by the load.

The net power is calculated by the agent

$$P_N = \sum_{i=1}^G P_{DG} - P_L \tag{7}$$

### III. UPPER-LEVEL MULTI-AGENT

The most imperative tasks of the upper level agent are to constitute energy management strategies, along with the energy management strategies, to assign producing power to each unit agent of distributed energy resource.

The communication network  $G = (V, E)$  over the MG is a weighted-balanced directed graph with  $n$  agents, where  $V = \{V_1, V_2, \dots, V_n\}$  denotes the agent set and  $E$  is the edge set. It is presumed that there occurs a coordinated way to connect any pair of agents. In the communication network, both agents have ingoing and outgoing edges the communication network is weighted-balanced for all agents. The inclusive information in this communication network is gathered utilizing consensus algorithm attained from the neighboring agent. Based on the inclusive information, the automatic reference set point control value is provided for the controller to operate the MG to function in a consistent state. This accumulation of information from other agent affords coordinated power flow from the DGs.

The distributed MAS provides the overall information concerning the states and voltage/frequency of numerous DGs collected based using consensus algorithm and provides automatic reference set point control value for the controller to regulate the MG to function in a steady state. Thus, the distributed MAS provides the overall information of the system and controllers in the system provide steady operation for MG.

#### A. Consensus Algorithm:

The consensus algorithm collects data from neighboring agent and entails agreement among the

various agents to activate on a single data value. The consensus protocols are fault tolerant and versatile. The agents must by some means publish their aspirant values about the voltage, communicate with each another, and settle on a single voltage consensus value. The consensus problem is a basic issue responsible for control of multi-agent systems. One way to deal with generating consensus is for all agents to settle on an optimal value. The output obtained using a consensus protocol needs to be the input value for the process. Another requirement is that agent may decide a output value only once and this decision is irreversible. Every agent decides at most one value, and if it decides some voltage value  $V_i$ , then voltage  $V_i$  must have been proposed by some process. The decided value  $a_s$  is provided as the reference input for the DG voltage.

$$\text{where } a_s = \frac{\sum_{i=1}^n V_i}{n} \tag{8}$$

where  $n$  is the number of DG in the communication network;  $V_i$  is the voltage value obtained from the  $n$  number of DGs. This referenced voltage  $a_s$  restores the voltage to operate on the grid codes based on the information obtained from the neighboring agents. The collection of data provides optimal solution for coordinated power flow among DGs in the network.

Consensus algorithm depends on the local information of each agent to guarantee the important information be shared in a distributed way. This algorithm collects the information about the voltage/frequency, power of various DG. Based on this information, the agent provides optimal solution for set-point trajectory to operate grid in steady state. According to the consensus algorithm, the information updating process of agent  $Agent_{DG_i}$  is represented as

$$Agent_{DG_i} = f_{t+1} = \sum_{i=1}^n df_i \tag{9}$$

where  $f_i$  is the local information about the voltage, frequency and power obtained from the  $i^{th}$  agent at the iteration  $t$ ;  $f_{t+1}$  is the updation of  $f_i$  at iteration  $t+1$  and  $d$  is the communication coefficient of between agents. This communication coefficient  $d$  provides guaranteed convergence speed. Based on this algorithm, the reference set point tracking is provided to maintain the generation of the power from DGs.

IV. PROPOSED MA BASED LOWER-LEVEL CONTROL STRATEGY FOR MG

A. Adaptive Robust Set-point Tracking, Disturbance Rejection (ARSPTDR) Controller to spot power deviancy

The ARSPTDR controller contains the features of MPC and PID controller. This controller provides superior performance that operates the system in steady state. The input to the controller is automatic reference value  $a_s$  generated via *Agent<sub>DG</sub>*. Figure 2 shows the ARSPTDR controller for inverter to operate the system in both grid-connected and transient mode. Adaptive Robust Set point Tracking, Disturbance Rejection (ARSPTDR) controller with predictive linear quadratic estimation is utilized for detecting and controlling the inverter for various grid operating modes. ARSPTDR controller for set point tracking and predictive linear quadratic estimation is for predicting the state estimation and correct those errors. The predictive linear quadratic estimation mechanism exhibits the central nervous system's control of movement. Owing to the time interruption between issuing commands and receiving sensory feedback, usage of the estimator supports the realistic model for making estimates of the current state of the system and issuing updated commands.

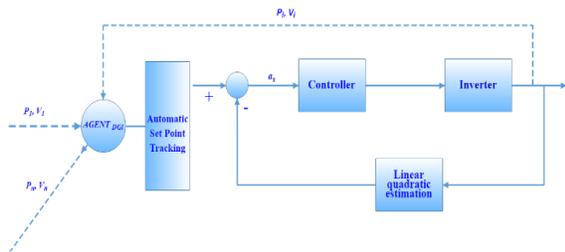


Figure 2: ARSPTDR controller for steady state operation

The state space model for the inverter is defined as

$$a_i = \mathfrak{R}_i a_{i-1} + \mathfrak{S}_i u_k + w_k \tag{10}$$

$$b_i = \Xi_i a_i + v_k \tag{11}$$

Model Prediction Output:

$$\hat{a}_{i+1} = \mathfrak{R}_i \hat{a}_i + K_g (b_i - \Xi_i \hat{a}_i) \tag{12}$$

Model Prediction Update:

$$e_i = \hat{a}_i - \hat{a}_{i+1} \tag{13}$$

$$P_i = P_{i-1} - G_i \Xi_i P_{i-1} \tag{14}$$

$$P_{i+1} = \mathfrak{R}_i P_i \mathfrak{R}_i^T - G_i \Xi_i P_i \mathfrak{R}_i^T + Q_k \tag{15}$$

$$\hat{a}_{i+1} = \hat{a}_{i+1} + P_{i+1} \tag{16}$$

B. Control Law:

The future set-point trajectory reference value is

$$a_i^* = \theta_t \hat{a}_{i+1} + (1 - \theta_t) a_s \tag{17}$$

where  $\theta_t$  is the tuning parameter for set-point trajectory and it can vary from 0 and 1.  $a_s$  is the automatic referenced voltage value provided by the Agent of  $n^{\text{th}}$  DG using consensus algorithm.

C. Optimal Selective Harmonic Elimination-Pulse Width Modulation (OSHE-PWM) for Harmonic elimination:

Harmonics distortion will increase the root mean square error in the electrical system and decline the power superiority. These stress the electrical network that could theoretically destruct the equipment. They may interrupt the typical process of the devices and upsurge operating costs. Thus, reducing those harmonic distortion is important concern. Hence, for reducing the harmonic distortion, various filters were utilized such as LC filter, LCL filter, etc. These filters require additional circuit for the topology, which diminishes the efficacy of the system. SHE method determines the suitable switching angles to exclude the number of low-order harmonics so that Total Harmonic Distortion (THD) is reduced. Hence, SHE based OPWM is done for reducing the harmonic deviation. The OPWM contains virtual bees' optimization algorithm for finding the switching angle with less THD. This will provide the quality for global best solution in finding the angle and diminish the harmonic distortion so that the eminence of the power will be improved.

The output voltage waveform of inverter is expressed in terms of Fourier series is given as

$$V_{out} = \sum_{y=1,3,..}^{\infty} V_y \sin y\theta \tag{18}$$

where

$$V_y = \frac{4V_{dc}}{y\pi} \left( V_1 \sum_{j=1}^{P_1} (-1)^{j+1} \cos y\theta_j + V_2 \sum_{j=P_1+1}^{P_2} (-1)^j \cos y\theta_j + \dots + V_M \sum_{j=P_{(M-1)}}^{P_M} (-1)^j \cos y\theta_j \right) \tag{19}$$

where  $y = 1, 3, 5 \dots 2N-1$  for the single-phase system;  $G$  is the number of dc sources in the converter and the product of  $V_G V_{dc}$  is the value of  $G$ th dc source.

$$P_{uM} = N_1 + N_2 + \dots + N_G \tag{20}$$

where  $N_1, N_2, N_3 \dots, N_G$  is the number of pulses per-quarter cycle at converter 1, 2, ...  $G$ .

The modulation index  $M_{index}$  is defined as

$$M_{index} = \frac{V_y}{GV_{dc}} \text{ where } 0 \leq M_{index} \leq 1$$

$V_{dc}$  is the input dc voltage source of each converter cell. These optimal switching angles are obtained by minimizing the constraint.

$$0 \leq \theta_1 \leq \theta_2 \leq \dots \leq \theta_N \leq \frac{\pi}{2} \tag{21}$$

The obtained switching angles are stored in the lookup tables to control the converter for a certain operating point. Hence, the harmonics are eliminated in the output voltage.

**D. Virtual Bee Algorithm:**

The Virtual Bee Algorithm (VBA) is based on social insects and begins with an initial populace of virtual bees, each bee haphazardly wanders in the space. The core steps of the virtual bee algorithm for function optimizations are: 1) creating a populace of virtual bees, each bee is allied with a memory bank; 2) encoding of the optimization functions and converting into the virtual food; 3) defining a criterion for communication and fitness function 4) updating a populace of individuals to new positions for searching virtual food; 5) after assured time of development, best estimate is obtained 6) decoding the results to attain the solution to the problem.

1) Create initial populace of virtual bees  $N_G$  possible solutions are initialized. Each solution is taken as a real-valued vector with their dimensions analogous to the number of variables of virtual food  $\theta_1, \theta_2, \dots, \theta_N$ .

2) The fitness score for each way out vector is assessed. In order to reduce the harmonics, the fitness function is defined as

$$F(x) = \min[THD] \tag{22}$$

where

$$THD = \left[ \frac{1}{V_1^2} \sum_{y=1,3}^{\infty} (V_y / y)^2 \right]^{1/2} \tag{23}$$

The individual harmonics are figured with these random values which denote the fitness of the search

point. The finest combination of angles among the populace of search points at certain iteration is selected.

3) Communicating the food location with the neighbors.

4) Update the finest solutions for switching angles.

5) Interpret the outcomes of the optimal switching angles.

**V. SIMULATION RESULTS AND DISCUSSION**

An overall control strategy for power management among different renewable energy sources in MG is modeled. The MG consists of DGs that are intermittent in nature, loads, energy storage system. Also, the converters are interfaced with DGs, which are difficult to control. Existing controller requires optimization algorithm and complex tuning process. So ARSPTDR controller is proposed to overcome these disadvantages and provide stable system operation. Our proposed work has been implemented in the MATLAB/SIMULINK platform of version R2015 with the system configurations of Intel core i3 processor, 8 GB RAM and Windows 7 Operating system. The simulation model of the MG shown in Figure 3 is realized in Matlab/Simulink. The MG is tested under different simulation scenarios to evaluate its capabilities when operating in grid-connected and islanded from the main grid. Different types of linear and nonlinear loads are considered in the studies. The system parameters are given in Table 1.

Table 1 shows the parameters of each agent in the communication network. It defines the maximum power generated by each DG sources.

Table 1: Agent Parameters

Agents	$P_1^{\min}(\text{kW})$	$P_1^{\max}(\text{kW})$
Agent 1	200	500
Agent 2	100	300
Agent 3	100	400
Agent 4	50	300
Agent 5	200	600

Since the resources and loads in a MG may be highly distributed in space, a comprehensive power management strategy is necessary for controlling the multiple terminals coordinately. The functions of such management include regulating power flow, ensuring stability, enhancing power quality, pursuing economic

benefits, etc. The loads and generators in AC MGs are commonly interconnected by power electronic converters, which can handle higher voltage variations than conventional electric machines. This proposed work aims to provide control strategy for power management of the MG that improves the power quality and maintains the stability of the system via ARSPTDR with OSHE-PWM.

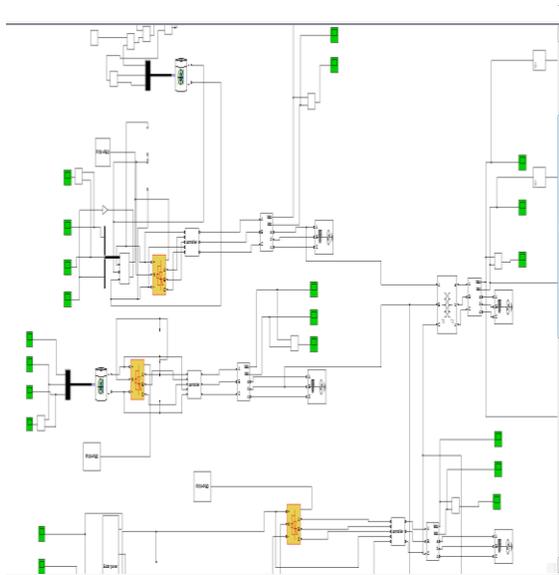


Figure 3: Simulink model of proposed system

A. Test Case I: Power quality improvement with load sharing and cost analysis during grid-connected operation

The stochastic load demand and renewable power generations were considered. The control system through the described Adaptive Robust Set point Tracking, Disturbance Rejection (ARSPTDR) controller with OSHE-PWM and the consensus communication algorithms were implemented in the model. The parameters for these DERs are specified in Table 1. The net power profile is similar to the residential load profile, because of major solar and wind power outputs make up for a major portion of loads. During grid-connected operation, the DG units in MG are required to afford power for the loads to lessen the burden of conventional generation and the power delivery directly from the main grid. This test case exhibits how the power flows are accomplished among the main grid, the DG units, and the loads. Initially, the MG was exporting power to the external grid and the energy storage had already reached

equilibrium on its state of charge due to the fixed marginal cost. As the lower level control, the ARSPTDR controller provides stable operation to generate power to the main Grid. Then, as the upper level control, the consensus strategy takes over by adjusting the reference points of the DERs for coordinating the power flow in MG. In grid-connected mode, the cost for the power delivered is based on the main grid rate at \$0.171/kWh. In this test case, the required load demand and the cost analysis for the grid-connected MG is depicted in Table 2. This also demonstrates the competence of the DG units to enhance the power nature of the distribution network by compensating the harmonics in the load. In this test case, DG inverter 1 is controlled to make up for the harmonic load 1 because of the nonlinear three-phase load stack associated with the DG unit. In this way, the harmonics will not proliferate to the rest of the distribution network during grid-connected operation. The waveforms of the current, voltage and power delivered to load 1 by the distribution grid at the PCC, under this test case for 0.2 s are shown in Fig. 4. The unsteady measurement during the initialization for 0.02 s and 0.13 s shown in Fig. 4 (c) is due to the fact that the controller needs a period cycles to track the generated references. It shows the regulated power with less harmonic distortion while delivering the power to load.

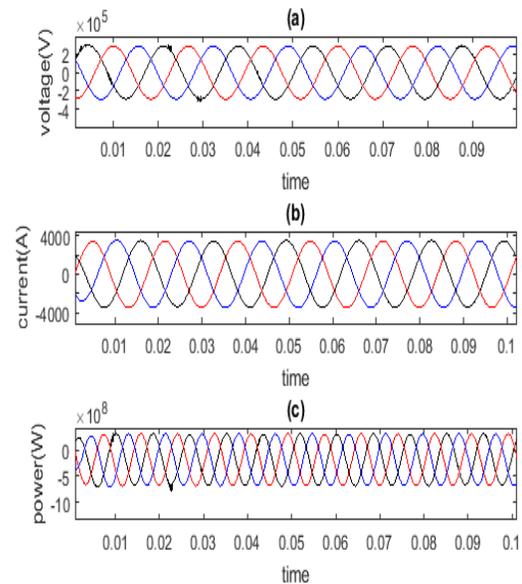


Figure 4: Output generated by grid a) current b) voltage c) power

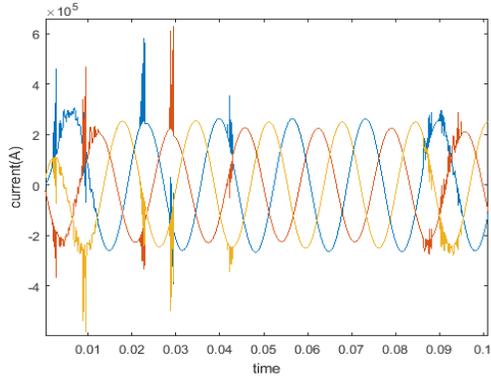


Figure 5: Current generated by load

During the initialization, large current transients are also observed as shown in Figure 5. In the simulation studies, it is assumed that with the current technology in the development of power electronic devices, the inverter will be able to withstand such large transients. During steady-state condition, the Total Harmonic Distortion (THD) value of is 5%, as shown in Figure 6. From Figure 6, it is evident that the THD value resulted from the proposed harmonic elimination method is significantly smaller with 5% THD than the existing methods in terms of both current and voltage. Various algorithms were implemented for reducing the harmonics deviation of the power using selective-harmonic elimination-pulse width modulation, in which solutions are not obtained for whole modulation ranges. So, the proposed OSHE-PWM provides optimal solutions and reduces the harmonics with low THD of 5% compared with the existing methods.

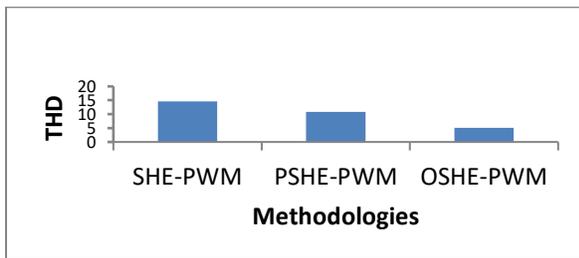


Figure 6: THD comparison

Table 2: Cost Analysis

Grid-connected MG		
LOAD	Load power(kWh)	Cost (\$)
1	200	34.2
2	300	51.3
3	100	17.1
4	150	25.65
5	170	29.07

**B. Test Case II: Power quality improvement with load sharing and cost analysis during islanded operation**

The second test case exhibits the islanded operation with power sharing among the standby DG units. In this test case, the MG is operating in the grid connected operation for 0.02 s. At 0.02 s, a fault occurs on the network of the main grid, and the circuit breaker activates to isolate connections of the MG from the main grid. The power delivered by DG inverter 1 for 0.2 s is shown in Figure 7. After the initiation of the islanding operation at 0.02 s, MG reaches steady-state operation in about 0.08 s. The waveform for 0.2 s is also shown in Figure 7. During islanded operation, the operating frequency of is reduced from 60 Hz (prior to islanding) to about 50 Hz for 0.08 s.

It can be seen that the cost directly relies on the islanded or grid-connected mode. In the event that the MG is operated in islanded mode, the cost of the requested net power will be high in order to benefit the utility providers. Table 3 shows the accumulated expenses for an islanded MG. Because of the additional power being produced amid the islanding event, the frequency of the system ascends above 60 Hz. The ARSPTDR control strategy for power management in MG predicts the variation in the initial frequency rise, then estimates a reference voltage value and thereby reducing the power outputs immediately of all dispatchable assets to protect the system from going beyond acceptable conditions. Also the cost analysis depicted in Table 3, when the MG is operated in islanded mode, it will benefit the utility providers to sell the power with high cost. Figure 7 shows the three-phase output current, voltage and power variations of the microgrid delivered to the load. The three-phase output contains less harmonic distortion. The microgrid delivers high output power with less harmonic ddistroction and provides steady state power without deviation.

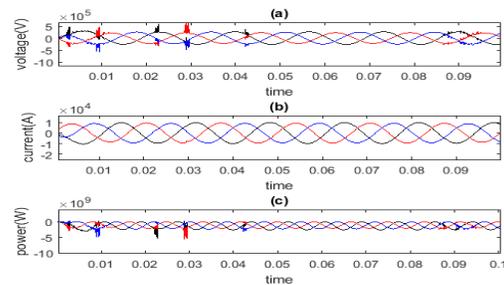


Figure 7: Output generated to load a) current b) voltage c) power

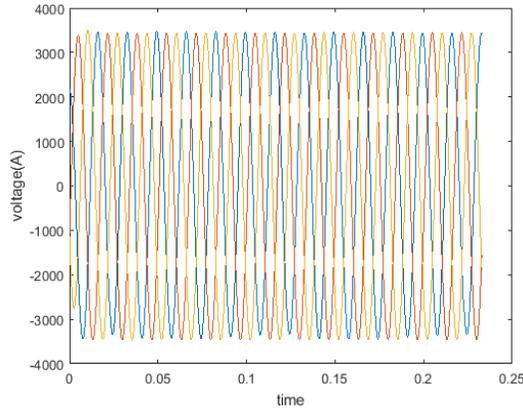


Figure 8: Inverter output voltage

Table 3: Cost Analysis

Islanded MG		
LOAD	Load power(kWh)	Cost (\$)
1	200	46
2	300	53
3	100	29
4	150	34.25
5	170	36.49

## VI. CONCLUSIONS

In this model, an overall control strategy for power management amongst diverse energy sources in a MG is modeled. The DG is connected with distributed multi-agent system for power management in MG, that control the voltage and adjusted the power in order to meet the demand. The existing methods have complex tuning process and require optimization, which are overcome by the proposed method. In communication network, utilizing consensus algorithm, it collects the information regarding voltage/frequency. Based on this information, the automatic reference set point tracking is provided for ARSPTDR with OSHE-PWM control system and restored the voltage/frequency of the MG. It shows that the proposed ARSPTDR with OSHE-PWM has eliminated harmonics and provides steady state power in intermittent nature of MG with reduced THD of 5% when compared with the existing approaches. A low-voltage network was implemented in MATLAB/SIMULINK environment and the simulation results provided in this paper show the superiority of the work and also the effectiveness of the control system.

## REFERENCES

- [1] Sam Koochi-Kamali, N.A. Rahim and H. Mokhlis (2014). Smart power management algorithm in Microgrid consisting of photovoltaic, diesel, and battery storage plants considering variations in sunlight, temperature, and load. *Energy Conversion and Management*, Elsevier, 84, pp.562-582.
- [2] Kaveh Dehghanpour and Hashem Nehrir (2017). Real-Time Multi Objective Microgrid Power Management Using Distributed Optimization in an Agent-Based Bargaining Framework. *IEEE Transactions on Smart Grid*, 99, pp1-1.
- [3] Yaser Karimi, Hashem Oraee and M. Josep Guerrero (2017). Decentralized Method for Load Sharing and Power Management in a Hybrid Single/Three-Phase-Islanded Microgrid Consisting of Hybrid Source PV/Battery Units. *IEEE Transactions on Power Electronics*, 32(8), pp.6135-6144.
- [4] Mohsen Hamzeh, Hossein Mokhtari and Houshang Karimi (2013). A decentralized self-adjusting control strategy for reactive power management in an islanded multi-bus MV Microgrid. *Journal of Electrical and Computer Engineering*, 36(1), pp.18-25.
- [5] Vivek Mohan, Jai Govind Singh, Weerakorn Ongsakul, Nimal Madhu and M.P. Reshma Suresh (2016). Economic and network feasible online power management for renewable energy integrated smart microgrid. *Sustainable Energy, Grids and Networks*, Elsevier.
- [6] Yunjie Gu, Wuhua Li and Xiangning He (2015). Frequency-Coordinating Virtual Impedance for Autonomous Power Management of DC Microgrid. *IEEE Transactions on Power Electronics*, 30(4), pp.2328-2337.
- [7] Qiuye Sun, Josep M. Janguo Zhou, Guerrero and Huaguang Zhang (2015). Hybrid Three-Phase/Single-Phase Microgrid Architecture with Power Management Capabilities. *IEEE Transactions on Power Electronics*, 30(10), pp.5964-5977.
- [8] C.M. Colson and M. Hashem Nehrir (2013). Comprehensive Real-Time Microgrid Power Management and Control with Distributed Agents. *IEEE Transactions on Smart Grid*, 4(1), pp.617-627.

- [9] Mahdi Shahparasti, Mustafa Mohamadian, Payam Teimourzadeh Baboli and Ali Yazdianp (2017). Toward Power Quality Management in Hybrid AC–DC Microgrid Using LTC-L Utility Interactive Inverter: Load Voltage–Grid Current Tradeoff. *IEEE Transactions on Smart Grid*, 8(2), pp.857-867.
- [10] Ritwik Majumder, Arindam Ghosh, Gerard Ledwich and Firuz Zare (2010). Power Management and Power Flow Control with Back-to-Back Converters in a Utility Connected Microgrid. *IEEE Transactions on Power Systems*, 25(2), pp.821-834.
- [11] Yan Li and Yun Wei Li (2011). Power Management of Inverter Interfaced Autonomous Microgrid Based on Virtual Frequency-Voltage Frame. *IEEE Transactions on Smart Grid*, 2(1), pp.30-40.
- [12] Hisham Mahmood, Dennis Michaelson and Jin Jiang (2015). Decentralized Power Management of a PV/Battery Hybrid Unit in a Droop-Controlled Islanded Microgrid. *IEEE Transactions on Power Electronics*, 30(12), pp.7215-7229.
- [13] T. Logenthiran, Dipti Srinivasan and M. Ashwin Khambadkone (2011). Multi-agent system for energy resource scheduling of integrated microgrids in a distributed system. *Electric Power Systems Research*, Elsevier, 81, pp.138-148.
- [14] [Christos-Spyridon Karavas, George Kyriakarakos, Konstantinos G. Arvanitis and George Papadakis (2015). A multi-agent decentralized energy management system based on distributed intelligence for the design and control of autonomous poly generation micro grids. *Energy Conversion and Management*, Elsevier, 103, pp.166-179.
- [15] Zhongwen Li, Chuanzhi Zang, Peng Zeng, Haibin Yu, and Hepeng Li, Member (2016). MAS Based Distributed Automatic Generation Control for Cyber-Physical Micro Grid System. *IEEE/CAA Journal of Automatica Sinica*, 3(1), pp.78-89.
- [16] H. S. V. S. Kumar Nunna and and Suryanarayana Doolla (2013). Multi Agent based Distributed Energy Resource Management for Intelligent Microgrids. *IEEE Transactions on Industrial Electronics*, 60(4), pp.1678-1687.
- [17] Tianqiao Zhao, Zhengtao Ding (2017). Distributed Finite-Time Optimal Resource Management for Microgrids Based on Multi-Agent Framework. *IEEE Transactions on Industrial Electronics*, 99, pp.1-1.
- [18] Y. S. Foo. Eddy, H. B. Gooi and S. X. Chen (2015). Multi-Agent System for Distributed Management of Microgrids. *IEEE Transactions on Power Systems*, 30(1), pp.24-34.
- [19] Chun-Xia Dou and Bin Liu (2013). Multi-Agent Based Hierarchical Hybrid Control for Smart Micro grid. *IEEE Transactions on Smart Grid*, 4(2), pp.771-778.