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Power Management Policies in Distributed Generation and Potential Opportunities for Future Research

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Abstract: ***In this paper widespread prior-art search of the distributed generation and its power management policies are presented, the conclusions derived by various authors for different objective statements are explored. In Microgrids with non conventional distributed generation systems, power quality issues are increasing due to power electronic converters involved for the energy conversion. Hence, the purpose of this paper is to showcase the unmet needs of the microgrids in terms of power quality problems and succeeded by the case study on the different available compensation techniques, algorithms and devices. Finally, reflected the importunate gaps available and promising opportunities for future research.***

Keywords: Microgrids; Distributed Generators; Reactive power compensation; Custom power devices; DSTATCOM; FACTS

Nomenclature

Abbreviations:

C:	Capacitor
PV:	Photovoltaic
MG:	Microgrid
RPC:	Reactive Power Compensation
VAR:	Volt-Ampere Reactive
FACTS:	Flexible AC Transmission Systems
CPD:	Custom Power Devices
DSTATCOM:	Distributed STATic COMpensator
DVR:	Dynamic Voltage Regulator
SVC:	Static VAR Compensator
UPQC:	Unified Power Quality Conditioner
IPFC:	Interline Power Flow Controller
I-UPQC:	interline UPQC
MGVS:	Microgrid Voltage Stabilizer
APF:	Active Power Filter
TCR:	Thyristor Controlled Reactor
TSC:	Thyristor Switched Capacitor
BESS:	Battery Energy Storage System
VFC:	Voltage and Frequency Controller
IELC:	Improved Electronic Load Controller
AUPQS:	Advanced Universal Power Quality Conditioning System
OLTC:	On Load Tap Changer
SP:	Smith Predictor
MPC:	Model Predictive controller
DN:	Distributed Network
ELC:	Electrical Losses Cost
TNP:	Total Net Profit

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I. INTRODUCTION

Micro-grid is a combination of small voltage distribution networks with alternate energy assets (fuel cells, wind, solar, etc.) jointly with energy storage utensils (DC capacitors and regular batteries) and loads. It should be competent enough to handle both usual state (grid-online) and abnormal state (grid-disconnected) operations. The diversity between a Microgrid and a regular grid pierce by small energy-sources is mainly in the approach of control and harmonization of accessible reserves. If the grid to be succeeded as described in [1], it must meet basic four performance requirements.

• A modern microgrid performs the critical analysis to anticipate the abnormalities before they happen and to assess them as they increase.

• It may take days or weeks to return today's grid to full operation after the crisis situations. A modern grid restores quickly and at lower cost as better information, control and communications tools available to support the operators and field personnel.

• With a modern grid, operators can realize the state and mode of the grid, provide suggestions for desire operation, and allow proper controls to be adopted.

• The modern grid provides new tools to understand situations, evaluate options and apply a wide band of control options to enhance grid performance from reliability, environmental, efficiency and economic aspects.

The microgrid will enhance the quality of power required by today's users, as per the defined industry standards. These standards will motivate the grid and customer to balance load and power-quality at an equitable price. Two factors negatively affect power quality. One is the power transfer from generation to the load via distribution network and the second one is disturbance in the electrical current wave due to AC to DC conversion at load side which creates voltage disturbances, current harmonics, reactive power issue (RPC), current unhinge & passage of neutral currents. [2].

Poor power quality reduces the life period and performance of the grid. For example, harmonic currents with poor power quality generate no useful power yet produce electrical losses that must be drawn from grid by increasing electrical generation. Among all these disturbances, reactive power unbalance is discussed as a major issue in this paper. The power system functions on AC system and majority of the loads applied on a daily basis require reactive power. Thus VAR management is considered as the strategy of reactive compensation to improve the concert of the AC system. The challenge of reactive power issue is analyzed from two approaches: load and voltage maintenance [3]. The goal is to acquire a unity power factor and active power poise from the load viewpoint, while the voltage sustain is important to minimize voltage disturbances at a given node of a distribution line. In both the models, the reactive power transmits through the microgrid has to be absolutely coordinated and controlled.

The intention of this work is to express the necessity to act in an competent way to the control of electrical parameters varied by the reactive power required by loads in the local distribution structure with significantly inductive in nature. The purpose of demonstrating this investigation on microgrid with alternate energy resources will also be explained, because in the coming trends the distribution grids are designated as self-reliant grids with advanced and conventional resources. This kind of micro-grid configurations that can be autonomous requires a specific investigation in the reactive power management due to the two-way power transmits that available in these grids. This paper mainly focuses on review of different outcomes considered by the authors to formulate the problem statement and strategies adopted to solve those problems. This paper also investigates the purpose of using custom power devices to compensate the reactive power, specifically presents a survey report on DSTATCOM and discusses on the persistent gaps available in them which can be considered for future research.

II. ANALYSIS OF THE PARAMETERS AND APPROACHES CONSIDERED AS OBJECTIVE FUNCTIONS

The power flow with high efficiency and good performance in micro-grids is a critical approach that relies on various parameters, as these structures consists of various kinds of grid architectures, variety of topology features, parallel networking, loads of various characteristics and lines with no transpositions. The factors associated with the issue of reactive power may be categorized as loss of power & energy in MGs, betterment of power factor, enhancement of voltage profile, harmonic reduction, energy storage and cost analysis of compensating devices.

The bibliographic survey of research papers analyzed and represented in the figure 1: [04-06]. Fig. 1 presents the priority taken by the authors about the thematic approaches to address the issue regarding control of reactive in micro-grids supported on the efficiency of reactive flow management in the line. It can be analyzed that the predominantly regarded parameter is energy losses and the others like voltage profile, cost and power factor follows in a descending order.

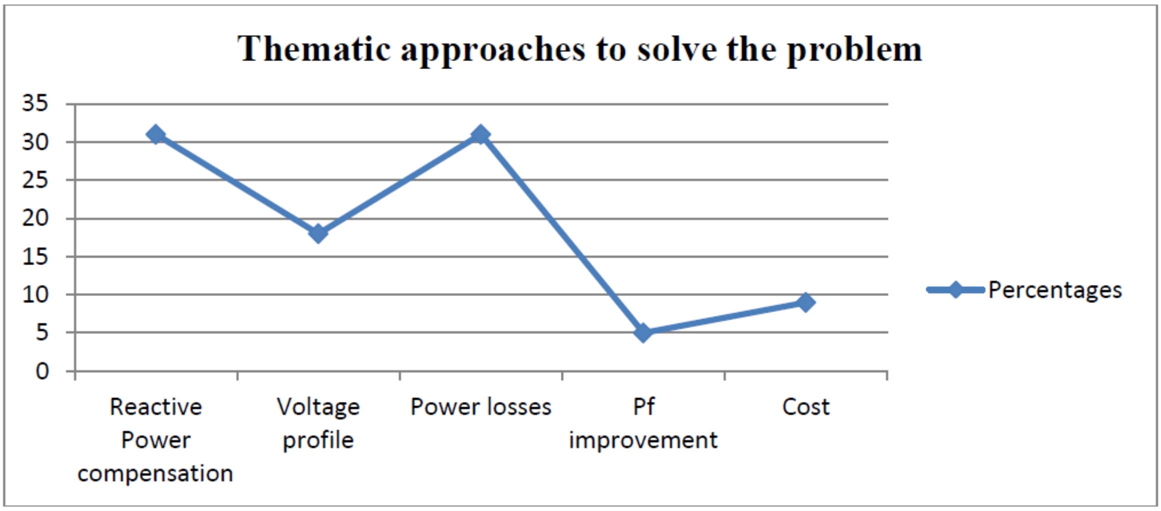

Fig. 1

Considering the same review, we can compare the objectives taken as a result of the authors for defining the problem of reactive power compensation. Fig. 2 shows the graphical representation of the analysis of the problem approaches considered by the authors and 'voltage regulation' is the most considered objective function. From the review papers analyzed it can be confirmed that only few of them taken harmonic mitigation into consideration, but it is easy to justify that in some of the other papers this parameter is taken as a desired objective in the power management, specifically when controlling devices incorporated related to power converters, which injects a huge amount of frequency mismatch to the grid that should be considered during this sort of analysis [7,8].

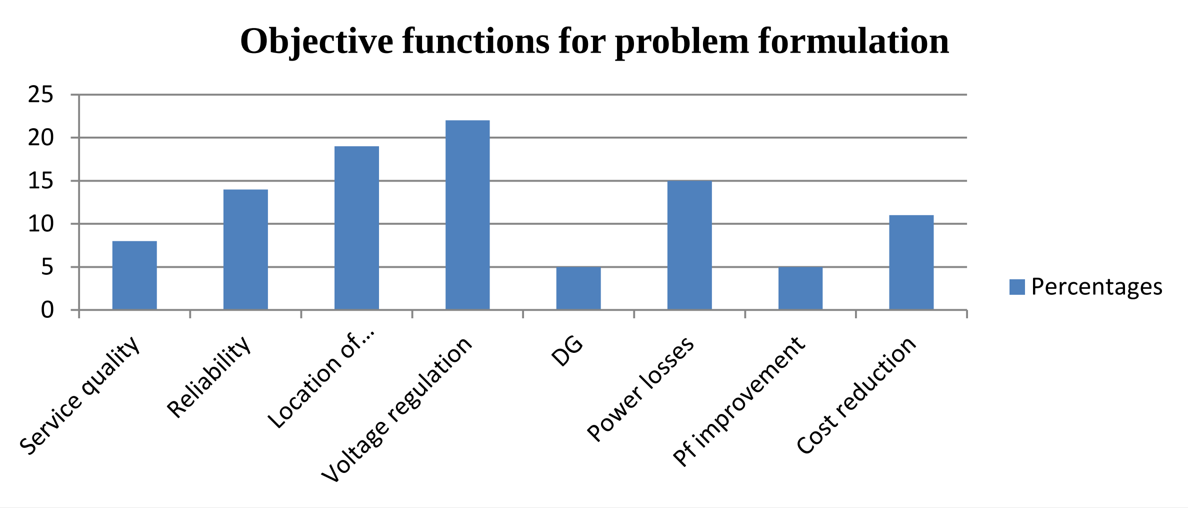

Fig.2

In distribution systems without compensation, the reactive energy flows will be absorbed inside grid and the reactive elements of obtained currents that require reactive loads flow during the network, generating more losses due to the thermal effect. Due to this reason, the power management, subject to the optimum collection and placement of controlling devices, is a great significance in diminishing of energy and power losses. The appropriate placement of controlling devices allows the flow of power into the microgrid, thus stopping from being sent by the grid with unnecessary values in the closed loop currents.

To solve the challenge of appropriate selection and placement of reactive power controlling gadgets in micro-grids, few models from heuristics and meta-heuristics discussed, they acts as learning algorithms by considering the approach of connecting points and lines of the distribution system. The frequently used algorithms to resolve this kind of issues some are shortlisted as Mixed Integer Nonlinear Programming Simulated Annealing, Ant Colony Optimization, Tabu Search, Particle Swarm Optimization, and Genetic Algorithms among many others. [9]

The FACTS controllers offer quick and trustworthy control on the variables, i.e., voltage, ohmic value of the line and phase difference between the given voltage and obtained voltage (Hingorani and Gyugy, 1999). In addition to that, the custom power device (CPD) is for medium and below medium voltage profile and improving the stability and quality of the source affecting finely tuned loads. FACTS devices are synonyms to CPDs. It is a CPD which is more in acceptance during these days due to its significant features like it responds quickly, applicable for complex load performance or voltage variation and the mechanization flexibility [10]. The CPDs used for the mitigation of the various quality concerns in the micro-grid are discussed in the subsequent section.

III. REACTIVE POWER COMPENSATION USING CUSTOM POWER DEVICES

Custom power designed product (CPDs) can be installed; at an equitable cost to obtain good quality of power and better support of the microgrid in both grid-online mode and autonomous mode. CPDs are famous controllers and can contribute simple way out for the control of reactive and distorted loading in the microgrid. By the usage of CPD in the microgrid system, we can improve the energy reserves and also it supports in increasing the quality of the whole system.

The below table presents an elaborative bibliographical research made, considering many journals database like IEEE Xplore, Science Direct, and Scopus specific compared to others. This prior art search goals at differentiating the methodologies and devices proposed by the various authors to address the power management issues and with this analysis to conclude the various multi-objective proposals with respect to the micro-grid cases studied, and the number of parameters represented in all the proposed strategies.

Table.1 Comparison of different custom power devices

Reference papers	FACTS/CPD devices	Controllable parameters
11	DG+DSTATCOM	Active and Reactive Power
12	UPFC	Stability
13	MGVS	Voltage profile
14	SVC+APF	Voltage regulation, current harmionics and power factor
15	SVC+TCR+TSC	Voltage regulation and stability
16	STATCOM+BESS	Reliability
17	VFC+IELC	Active, reactive powers and THD
18	OLTC, C and DGs	Voltage regulation and power losses
19	DG+DSTATCOM	Improvement of bus voltages and reduction of losses

From the table.1, it can be justified that DSTATCOM is the most favorable device to progress overall concert of microgrid; it contributes in active & reactive power control, voltage profile improvement, power factor correction, reducing the losses and also cost savings. The next section will discuss in detail about the basic control algorithms used predominantly by different authors for operating DSTATCOM in a microgrid.

IV. REACTIVE POWER COMPENSATION USING DSTATCOM

The efficiency of the DSTATCOM is based upon the modeling and voltage control algorithms, i.e., the control of power and attainment of current modules respectively. For this reason, there are various strategies which are published in the journalism and of them the fundamental ones are instantaneous power theory, instant compensation, d-q theory and modeling foundational on per phase concept and the neural network scheme. Among the proposed strategies, IRP and SRF schemes are predominantly implemented in the control of the microgrid.

A DSTATCOM is an efficient device controlling either voltage profile or line current. If they drives in a voltage variable approach, it can control the bus voltage to which they are connected a perfect ac, instead of the distortion and deviation in voltage in the source face or line current. Likewise when controlled in a current approach, it can change the supply side currents as balanced ac. DSTATCOM can be designed using an Inverter and a DC link capacitor. The basic need of a DSTATCOM in a 3-phase 4-wire distribution network is, it is competent of feeding three distorted and deflected currents towards the AC system, to nullify voltage or current perversions. We therefore require a DSTATCOM capable to inject three individual currents into 3 phases. The issue of using a basic 3-phase bridge configuration inverter as the power module of the DSTATCOM is equal to the sum of 3 currents should be zero.

The basic three concepts predominantly adopted for controlling the DSTATCOM in the micro-grid operations are p-q theory, d-q theory and Adaline- based theory.

a) p-q Theory

p-q theory is generally termed as Instantaneous Reactive Power theory (IRP) is basically changing of three-phase parameters to two-phase parameters in α–β platform and the computation of instantaneous active and reactive power in this platform. The three phase inputs that are voltages and currents are applied to the controller (PI) and developed to produce base current commands and are given to PWM circuit to produce switching pulses fed to DSTATCOM. Parks transformation is used to convert quantities ie. α–β platform to d-q frame. These two phase signals will be converted to three phase using inverse parks transformation.

b) d-q Theory

d-q theory is generally termed as Synchronous Reference Frame (SRF) theory discusses about the makeover of currents in synchronously revolving d–q frame. Here three 3 input voltages are supplied to the PI controller and then controlled by Phase Locked Loop to produce sinusoidal and co sinusoidal signals. Current pulses are fed to the PWM generator to produce switching signals. Reactive power compensation can be possible by making the component of q-axis as zero while obtaining reference currents.

c) LMS theory

Least Mean Square theory is based on the algorithm of calculating weights using minimum error concept. Here neural network is trained using Adaline which targets the unit weighted vectors to maintain lowest error. Weight depends on the load current and phase voltage. Reference current is decomposed into two components, first component is calculated based on positive sequence currents and the second component is calculated based on the dc bus voltage error. This control scheme ends in the adjustment of sluggish changing supply current (with respect to DSTATCOM currents), so needs fewer calculation pains and also this strategy manages on its own the estimation delay produced by the processor.

Though all the techniques gives satisfactory results, Adaline-based method uses LMS algorithm to compute the associated weights, and these computations are calculated online; so, the scheme is competent to deduce the reference currents from dynamic load scenarios, which doesn't happen with remaining artificial intelligence dependent current generation strategies.

V. DISCUSSION ON POTENTIAL OPPORTUNITIES FOR FUTURE RESEARCH

All the strategies, FACTS devices and control schemes discussed as a prior art search for the problem identified are not considering the realistic geographical placement of distributed generators and compensators, most of the authors analyzed the concepts based on the assumption that all DGs are located close to each other.

From the bibliographic survey, it is observed that all of the mentioned control strategies have their individual features, rewards and limitations. Microgrids will become more popular when the issues of active and reactive power management are satisfactorily resolved. The upcoming inclination on MG study and implementation may be sum up as follows.

A. Enhance the strength and stability of Microgrids

With a major deployment of the DGs, the investigation about how to comprehend exact active and reactive power distribution among parallel DGs, enhance the strength and stability of Microgrid and at the same time reduce the power flow complexities using the predictive control, graph theory & multi-agent networks have been a typical trend.

B. Power management strategies in Microgrids with dynamic loads

The schemes for active and reactive power allotment of microgrids using static load are fine addressed, still it is complicate to make certain the reactive power distribution when grids deliver dynamic motors like induction motor, variable loadings and the hybrid electric transportation, etc. The accomplishment of the reactive power controlling in such complex motors is the significant aspects in the prospect study.

C. Economical control strategies

This is a key issue to optimize the functional cost and manage sustaining activities, at the same time improving the dependability and manageability of grids. So, minimization of MG price parameter is one of the tendencies in the further investigations.

D. Eliminate the brunt of communication interruption

The managing schemes are always concerned to the communication of information, when many DGs are parallel connected; still the interruption is unavoidable in small and large bandwidth networks. So, it is significant to allow power distribution issue for the constant, restricted, or accidental delay.

The best way to reduce the price and improve the delay target level is also a challenging examine topic of microgrids in the next step which can reflect substantial improvement in the microgrid performance.

Table.2 Advantages and Limitations of various Control Strategies reflecting the impact of Communication Delay

Variable schemes	Systems considered	Benefits	Limitations
Gain scheduling method	The information of the MGCC is accustomed using the gain scheduler	●Minimize the price by proposing the realistic price function ●The scheme can promise a better power allocation on the delay boundary	●Gain constants are difficult to choose ●Communication impediment in reactive energy compensators is not measured ●Information crash not taken into account
Predictive control	Envisage the indefinite wait by the SP or MPC	●Perfect design to the constant communication delay ●The system will assure a best power distribution on the delay boundary	●Algorithm is intricate ●Cannot consider with the issues set by arbitrary interruption
Supportive distributed control	A sparse structure is required to distribute the active and reactive energies using the disseminated scheme	●The resultant active and reactive power management will be attained using dynamic load circumstances ●Have flexibility to a unique communication link breakdown ●Better toughness to the steady communication interruption	●Data leak is not dealt with ●Cannot solve the challenges set due to accidental delay ●Required reactive power management difficult to achieve

VI. CONCLUSION

Microgrids consist of numerous parallel operated DGs with coordinated control schemes, which formulate them to function both in grid-associated and grid-disconnected modes. The limitations of conventional methods used for power sharing are presented in this paper. Paper summarizes the various reactive power compensation schemes and their advantages and limitations. Though DSTATCOM is concluded as the better custom power device to improve the microgrid performance, authors doesn't consider the realistic geographical placement of DGs and DSTATCOM. Most of the existing solutions consider the low bandwidth communication lines in the parallel control, which may cause communication delay between the DGs and Compensators. Finally the future scope of research is discussed which may minimize the impact of data delay and provide realistic information about voltage profile and power management.

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