An Extensive Survey on MOPSO-Based Optimal Control of Shunt Active Power Filter Using a Variable Structure Fuzzy Logic Sliding Mode Controller

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Abstract- The power demand always exceeds the available power generation in any developing country. Hence, renewable power generating systems such as PV and wind energy conversion systems are used to supplement the fossil fuel based power generation. Renewable Energy Sources (RESs) refer to the sustainable natural energy sources, such as the sun and the wind. Renewable energy systems convert these natural energy sources into consumable energy forms (electricity and heat), which are easy to transport and to use. But due to the non-linearity of the load that is diode bridge rectifier with RL- load, there is harmonics in the load currents. Hence, harmonics reduction and reactive power compensation simultaneously can be done by using a voltage source inverter connected in parallel with the system which acts as a shunt APF for reducing the distortions produced due to non-linear load in the load current. Active power filters are now seen as a viable alternative over the classical passive filters, to compensate harmonics and reactive power requirement of the non-linear loads. The objective of the active filtering is to solve these problems by combining with a much-reduced rating of the necessary passive components. This work presents an extensive survey of literature on power control strategy for hybrid (FC- PV-Wind-Battery) energy utilization scheme.

Keywords- shunt active power filter, MOPSO, Total Harmonic Distortion (THD). Sliding Mode Controller.

I. INTRODUCTION

Energy is essential to everyone’s life no matter when and where they are. This is especially true in this new century, where people keep pursuing higher quality of life. Among different types of energy, electric energy is one of the most important that people need every day. An overview is given on the world energy demand, electricity consumption and their development trend in the near future. The electric power generation technologies based on different energy sources are also reviewed in the work. Finally, the need for this research work is addressed and the scope of the research is also defined.

Due to the critical condition of industrial fuels which include oil, gas and others, the development of renewable energy sources is continuously improving. This is the reason why renewable energy sources have become more important these days. Few other reasons include advantages like abundant availability in nature, eco-friendly and recyclable. Many renewable energy sources like solar, wind, hydel and tidal are there. Among these renewable sources solar and wind energy are the world’s fastest growing energy resources. With no emission of pollutants, energy conversion is done through wind and PV cells.

Day by day, the demand for electricity is rapidly increasing. But the available base load plants are not able to supply electricity as per demand. So these energy sources can be used to bridge the gap between supply and demand during peak loads. This kind of small scale stand-alone power generating systems can also be used in remote areas where conventional power generation is impractical.

The ever increasing energy consumption, rapid progress in wind, PV and fuel cell power generation technologies, and the rising public awareness for environmental protection have turned alternative energy and distributed generation as promising research areas. Due to natural intermittent properties of wind and solar irradiation, stand-alone wind/PV renewable energy systems normally require energy storage devices or some other generation sources to form a hybrid system. Because some of renewable energy sources can complement each other, multi-source alternative energy systems (with proper control) have great potential to provide higher quality and more reliable power to customers than a system based on a single resource. However, the issues on optimal system configuration, proper power electronic interfaces and power management among different energy sources are not resolved yet. Therefore, more research work is needed on new alternative energy systems and their corresponding control strategies.

This active filter generates a compensating current which is of equal in magnitude as harmonic current and opposite in phase with it to reduce the harmonics present in the load current.APF is classified as series, shunt or combination both series and shunt but shunt APF is preferred here as the principle of the shunt APF is to produce compensating currents of equal in magnitude but opposite in- phase to those harmonics that are present due to non-linear loads. SAPF is a closed loop structure where non-linear loads act as linear. It can compensate reactive power and can also mitigate harmonics and distortions.

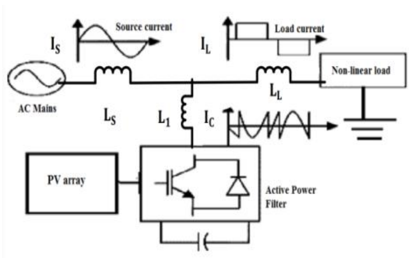

Figure 1.1 Principle of shunt APF.

Here, the shunt APF produced compensating currents of equal in magnitude but opposite in-phase to those harmonics that are present due to non-linear loads which results in mitigation of harmonics at load current. Generally, the voltage source inverters (VSI) are used to convert the power of the PV system to inject it to the distribution system. But here, the VSI act as a multifunctional device which is used for energy conversion and also for harmonics elimination as well as reactive power compensation simultaneously.

II. HYBRID POWER SYSTEM

Because of the intermittent and fluctuant availability of the renewable energy sources, Hybrid Power Systems (HPS) provide a high level of energy security through the mix of various generation systems and often incorporate energy storage systems to ensure maximum reliability of power supply. Several kinds of hybridization of power sources are presented as follows:

Hybridization of renewable energy sources and backup power units: Because of the intermittent availability of renewable energy sources, backup power units are usually integrated for a high level of local energy security. For example, diesel generator, micro gas turbine and fuel cells are usually used as for uninterrupted power supplies.

Hybridization of renewable primary sources: Two or more renewable primary sources can be associated for complementary advantages. For example, the PV-Wind system are often proposed, because the PV panels provide powers only in the day time and wind generators produce usually more powers with stronger wind in the night.

Hybridization of renewable energy sources and energy storage devices: The association of energy storage devices with renewable energy sources can ensure reliability and security of the distributed power generation system while maximizing the benefit from renewable energies. For these systems, the excess and deficit of energy production can be optimally adjusted by the energy storage units to increase the energy efficiency.

a. Concept of Active Generator

Conventional power plants are usually active generators because they are controllable and can supply necessary powers to satisfy the grid requirements. Moreover, they can usually provide some ancillary services to the grid, basically like frequency regulation by active power control, voltage regulation by reactive power control, etc… They are mostly fossil and nuclear fuelled and rely on the abundant fuel supply like coal, oil, natural gas or nuclear fuels. Most of the time, they can work at any power level below its nominal power (Fig.I-6a) by controlling the fuel supply.

Renewable energy generators are usually considered as passive generators because they can not participate to the grid management, because they are dependent on the availability of the primary renewable source. Most of the time, they work far below their nominal capacity (Fig.I-6b). Moreover, the reliability and efficiency of the power system can not be ensured.

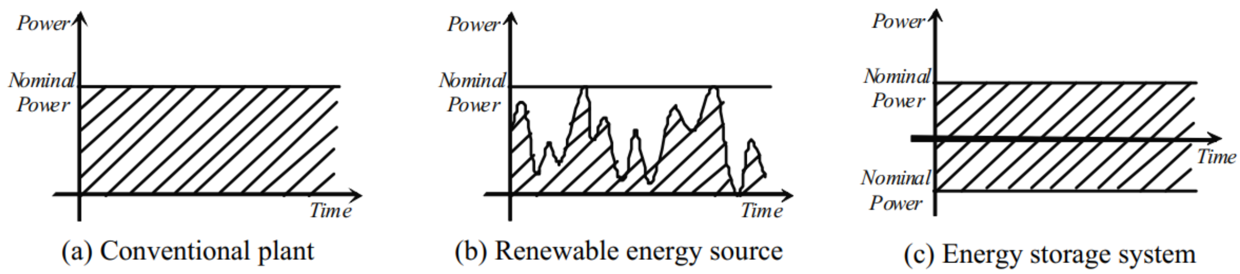

Figure 2.1 Characteristics of different kind of energy sources.

Therefore, they can not provide ancillary services to the grid, like power balance between the production and the consumption.

Energy storage devices can serve as backup power plants. They can work at any power level between two nominal powers, for storing and releasing energies (Fig.I-6c). So they can be used to support the operation of sources, transmission, distribution, and loads. When they serve as source devices, they can help to solve the problems of renewable energies' intermittent availabilities and fast transients.

For each unit, the classified power domain can be achieved by a proper control (Fig.2.1).

Thus, a hybrid power system combining a renewable energy based generator and energy storage devices can be a good solution to make an active generator. Such an active generator corresponds to both the needs of clean energy generation and high power quality for the future's electrical network. For this objective, two major innovative improvements should be made:

Energy Storage Systems should be well chosen and associated with renewable energy generators to compensate or to absorb the power difference between the actual renewable energy production and the required grid consumption;

Energy Management Strategies should be properly designed and adapted to control the power flows among the renewable energy generator, the energy storage systems and the grid. Various additional control functions have to be implemented to provide ancillary services for the grid.

III. LITERATURE REVIEW

SR. NO.	TITLE	AUTHORS	YEAR	APPROACH
1	MOPSO-based optimal control of shunt active power filter using a variable structure fuzzy logic sliding mode controller for hybrid (FC-PV-Wind-Battery) energy utilisation scheme	A. A. A. Elgammal and M. F. El-naggar,	2017	Proposed an effective concept for hybrid fuel cell-photovoltaic-wind-battery active power filter (FC-PV-Wind-Battery)
2	Comparative study between Sliding mode controller and Fuzzy Sliding mode controller in a speed control for doubly fed induction motor	S. Abderazak and N. Farid	2016	Reported a comparison between a Sliding mode controller and Fuzzy Sliding mode controller in a speed control for doubly fed induction motor
3	Torque ripple reduction of switched reluctance motor drive with adaptive sliding mode control and Particle Swarm Optimization	M. M. Namazi, M. M. Borujeni, A. Rashidi, S. M. S. Nejad and J. W. Ahn	2015	The control mechanism is composed of an adaptive sliding mode speed controller to determine the appropriate current command and a hysteresis current controller
4	Optimal four quadrant speed control of switched reluctance motor with torque ripple reduction based on EM-MOPSO	M. Mansouri Borujeni, A. Rashidi and S. M. Saghaeian Nejad,	2015	The control mechanism is composed of a Proportion-Integration (PI) speed controller and a hysteresis current controller
5	Fault Indicator Deployment in Distribution Systems Considering Available Control and Protection Devices: A Multi-Objective Formulation Approach	A. Shahsavari, S. M. Mazhari, A. Fereidunian and H. Lesani	2014	Introduces a multi-objective fault indicator (FI) placement method in electric distribution systems
6	Robust design of multimachine power system stabilizers using multi-objective PSO algorithm	Y. Welhazi, T. Guesmi, C. Dhifaoui and H. H. Abdallah	2014	Reported a robust design of multimachine power system stabilizers (PSSs) using multi-objective particle swarm optimization (MOPSO) is presented
7	New control strategy of unified power quality conditioner with sliding mode approach	R. K. Patjoshi and K. K. Mahapatra	2013	Presented a novel sliding mode method with the fuzzy controller approach in the development of unified power quality conditioner (UPQC) for reactive power

A. A. A. Elgammal and M. F. El-naggar, [1] This exploration presents an effective concept for hybrid fuel cell-photovoltaic-wind-battery active power filter (FC-PV-Wind-Battery) energy scheme based on the variable structure sliding mode fuzzy logic controller (SMFLC) using the multi-objective particle swarm optimisation (MOPSO). The parameters of the fuzzy logic control membership functions and the weighting factors of the SMFLC can be tuned by MOPSO in such an approach to optimise the dynamic performance of the shunt active power filter (SAPF) and minimise the total harmonic distortion (THD) of the source current waveform and voltage waveform of the hybrid (FC-PV-Wind-Battery). A group of objective functions was chosen to validate the dynamic performance of the SAPF and the effectiveness of the MOPSO-SMFLC. These selected fitness functions are: (i) minimising the error of the inverter capacitor DC voltage, (ii) minimising the THD of the output current and voltage of DC and AC sides and (iii) minimising the controller reaching time. A computer simulation study using Simulink/Matlab and experimental laboratory prototype were carried on to asses and compare the dynamic performance of the proposed MOPSO-SMFLC controller with the conventional proportional-integral-derivative, variable structure SMFLC, the feed-forward multilayer neural network controller and the variable structure SMFLC based on the single-objective particle swarm optimisation.

S. Abderazak and N. Farid, [2] This exploration presents a comparison between a Sliding mode controller and Fuzzy Sliding mode controller in a speed control for doubly fed induction motor. The fuzzy sliding mode controller is designed in order to improve the control performances and to reduce the chattering phenomenon. In this technique the saturation function is replaced by a fuzzy inference system to smooth the control action. The proposed scheme gives fast dynamic response with no overshoot and zero static error. To show the validity and the effectiveness of the control method. Simulation results showed that improvement made by our approach compared to conventional sliding mode control (SMC) with the presence of variations of the parameters of the motor, in particular the face of variation of moment of inertia and disturbances of load torque. The results show that the FSMC and SMC are robust against internal and external perturbations, but the FSMC is superior to SMC in eliminating chattering phenomena and response time.

M. M. Namazi, M. M. Borujeni, A. Rashidi, S. M. S. Nejad and J. W. Ahn, [3] In this inverstigation, for speed control with torque ripple minimization of switched reluctance motor drives an optimal speed controller based on Elitist-Mutated Multi-Objective Particle Swarm Optimization (EM-MOPSO) with good accuracies, and performances is presented. The control mechanism is composed of an adaptive sliding mode speed controller to determine the appropriate current command and a hysteresis current controller. In the adaptive sliding mode controller, the heuristic parameters are usually determined by a tedious and repetitive trial-and-error process. By using EM-MOPSO, the trial-and error process is eliminated. The optimal parameters of adaptive sliding mode controller and turn-on and turn-off angles are chosen by applying a multi-objective function, including both Integrals Squared Error (ISE) of speed and torque ripple. The performance of this EM-MOPSO based controller has been demonstrated by simulation in MATLAB/SIMULINK software for a four phases, 4-kw SRM.

M. Mansouri Borujeni, A. Rashidi and S. M. Saghaeian Nejad, [4] In this inverstigation, an optimal basic speed controller for switched reluctance motor (SRM) based on Elitist-Mutated Multi-Objective Particle Swarm Optimization (EM-MOPSO) with good accuracies, and performances is presented. The control mechanism is composed of a Proportion-Integration (PI) speed controller and a hysteresis current controller. Because of nonlinear characteristics of a SRM, EM-MOPSO is used to tune coefficients of PI speed controller, turn on and turn off angles along with maximum value of the phase current by applying a multi-objective function, including both Integrals Squared Error (ISE) of speed and torque ripple. This EM-MOPSO based controller simulated in SIMULINK/MATLAB software for a four phases, 4-kw SRM. The performances of the EM-MOPSO and PSO algorithm in tuning the controller parameters are compared with each other. Simulation results show that the EM-MOPSO based controller can better improve SRM performance such as torque ripple, dynamic response and copper losses.

A. Shahsavari, S. M. Mazhari, A. Fereidunian and H. Lesani,[5] This work introduces a multi-objective fault indicator (FI) placement method in electric distribution systems. The prevalent FI placement problem formulation is extended by considering effects of existing protection and control devices on customers' restoration time. Moreover, the customers' average restoration time index (CARTI) is proposed, as a new technical objective function with respect to uncertainties of automatic switching. Furthermore, a multi-objective solution approach is developed to simultaneously minimize indispensable economic and technical objectives. The resultant optimization problem is solved through a multi-objective particle swarm optimization (MOPSO) based algorithm, accompanied by a fuzzy decision making method to select the best result among the obtained Pareto optimal set of solutions. Assuming SAIDI and CARTI as technical objectives, the proposed method is applied to bus number four of the Roy Billinton test system (RBTS4), as well as a real-life distribution network with about 5500 customers, followed by a discussion on results.

Y. Welhazi, T. Guesmi, C. Dhifaoui and H. H. Abdallah,[6] In this work, robust design of multimachine power system stabilizers (PSSs) using multi-objective particle swarm optimization (MOPSO) is presented. The problem of selecting the stabilizer parameters is converted to an optimization problem with integral square error (ISE) and integral of time multiplied absolute value of the error (ITAE)-based objective functions. The MOPSO is employed to search for optimal PSS parameters for a wide range of operating conditions. The performance of the proposed MOPSO based PSSs is investigated for a three-machine nine-bus system under different configurations. The effectiveness of the proposed approach in enhancing the dynamic stability of power systems is confirmed through eigenvalue analysis and nonlinear simulation results.

R. K. Patjoshi and K. K. Mahapatra,[7] This work describes a novel sliding mode method with the fuzzy controller approach in the development of unified power quality conditioner (UPQC) for reactive power, harmonics and both symmetric and asymmetric sag and swell compensation. The UPQC consists of both shunt and series converter having a common dc link. The shunt converter eliminates current harmonics generated from the nonlinear load and the series converter suppresses the voltage sag and swell generated from the supply side. The dc link control strategy is based on fuzzy-logic controller where as sliding mode controller is used in the inner current control loop to dictate the gate signals for switching of the both converters. To determine the efficiency of UPQC model, it is implemented through MATLAB. The simulation results show the superior capability of the proposed approach in mitigating the effects of current harmonics and voltage sag and swell generated from the supply side.

IV. PROBLEM STATEMENT

Early equipment was designed to withstand disturbances such as lightning, short circuits, and sudden overloads without extra expenditure. Current power electronics (PE) prices would be much higher if the equipment was designed with the same robustness. Pollution has been introduced into power systems by nonlinear loads such as transformers and saturated coils; however, perturbation rate has never reached the present levels. Due to its nonlinear characteristics and fast switching, PE create most of the pollution issues. Most of the pollution issues are created due to the nonlinear characteristics and fast switching of PE. Increase in such non-linearity causes different undesirable features like low system efficiency and poor power factor. It also causes disturbance to other consumers and interference in nearby communication networks. The effect of such non-linearity may become sizeable over the next few years. Hence it is very important to overcome these undesirable features.

V. CONCLUSION

This work presents an extensive review on MOPSO-Based Optimal Control of Shunt Active Power Filter Using a Variable Structure Fuzzy Logic Sliding Mode Controller. The PQ issue is defined as “any occurrence manifested in voltage, current, or frequency deviations that results in damage, upset, failure, or misoperation of end-use equipment.” Almost all PQ issues are closely related with PE in almost every aspect of commercial, domestic, and industrial application. Equipment using power electronic devise are residential appliances like TVs, PCs etc. business and office equipment like copiers, printers etc. PE are the most important cause of harmonics, interharmonics, notches, and neutral currents. Equipment affected by harmonics includes transformers, motors, cables, interrupters, and capacitors (resonance). Power electronics are alive and well in useful applications to overcome distribution system problems. This brief discusses recent work on harmonic mitigation and power quality control.

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